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THE BIOLOGICAL CONTROL OF INSECT AND PLANT PESTS

A Report on the Organisation and Progress of the Work of Farnham House Laboratory

BY

W. R. THOMPSON, Ph.D., D.Sc.

Assistant Director, Imperial Bureau of Entomology, and Superintendent, Farnham House Laboratory.

JUNE, 1930.

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Farnham House Laboratory. [*Frontispiece*

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PREFACE.

FARNHAM HOUSE LABORATORY was founded by the Imperial Bureau of Entomology in 1927, by means of a grant from the Empire Marketing Board with, as its principal object, the furtherance of the control of the insect pests of agriculture and forestry, by what is known as the biological method, that is, by means of beneficial parasites and predators. A fifteen-roomed house at Farnham Royal, Bucks, situated about two and a half miles from the town of Slough, on the Great Western Railway, and about 25 miles from London, was purchased in February, 1927, and work begun there in June of the same year, on the parasites and predators of a number of pests of primary importance in various parts of the British Empire, under the control of Dr. S. A. Neave, who was succeeded a year later by Dr. W. R. Thompson, the present Superintendent.

That the creation of the Laboratory met a real need in Imperial Entomology, the response of the Dominion and Colonial entomologists to offers of assistance has amply proved. Requests for help were received even before the Laboratory had been opened for work, and since that time, the list of injurious insects and plants we have been asked to investigate in the hope of finding parasites or predators, which can be utilised in their control, has increased very rapidly, until it now comprises some 70 species. The programme of work originally covered only the natural enemies of injurious insects, but in 1929, at the request of the Government of the Dominion of New Zealand, the laboratory took over the conduct of the European investigations and practical operations on the insect enemies of certain weeds, which had hitherto been carried out under the supervision of Dr. A. D. Imms of Rothamsted and Professor J. W. H. Harrison of the University of Leeds.

In 1928, after visiting the Laboratory and inspecting its facilities, Dr. R. J. Tillyard, the Chief of the Federal Entomological Service of Australia, requested us to undertake the supervision of the work of three members of his staff, who had been assigned to the investigation of certain important entomological problems in Europe. Mr. J. W. Evans spent a year at the Laboratory, studying methods for the mass production of the egg-parasite, *Trichogramma*, with the object of utilising it against the Codling Moth in Australia. He completed his

investigations and returned to Australia early in June, 1929. Dr. F. G. Holdaway spent the winter of 1928 to 1929, studying the problem of the Sheep Blowfly, and is now continuing these investigations in Southern France, with the help of an assistant, Mr. A. C. Evans, specially appointed for this purpose. Mr. S. G. Garthside began in the autumn of 1928 his study of the insects attacking St. John's Wort (*Hypericum perforatum*), assisted by Mr. T. D. Boyd, and this work is still going on.

The rapid progress of the Laboratory and the heavy pressure of work which has thereby resulted, have made it, hitherto, impossible to prepare an account of the work which has been and is being carried out. It seems, however, desirable that the entomologists of the Empire should be made acquainted with the work undertaken by the Laboratory and the facilities it offers. This report has been designed to meet this need. It comprises a general account of the object and methods of work on biological control, a description of the organisation and facilities that the Laboratory now possesses for dealing with problems of this kind, and a brief summary of the investigations and practical work undertaken up to the present time.

GUY A. K. MARSHALL,

Director,
Imperial Bureau of Entomology.

CONTENTS.

	Page
LIST OF ILLUSTRATIONS	5
I. INTRODUCTION	6
II. THE PRINCIPLES AND ORGANISATION OF WORK ON BIOLOGICAL CONTROL	7
1. The Principles of Biological Control	7
2. Preparatory Work	12
3. Preliminary Field Survey	14
4. Examination of Sample Collections	18
5. Choice of Beneficial Species	24
6. Large Scale Collections and Shipments	29
7. Methods of Treatment on Reception	46
8. Study of the Progress of Introduced Parasites in the Field	53
9. The Results of Experiments in Biological Control	55
10. Summary	71
III. FARNHAM HOUSE LABORATORY: ITS RESOURCES, EQUIPMENT AND STAFF	73
1. Finance	73
2. Grounds, Buildings and Equipment	73
3. Staff	78
4. Summary	79
IV. PRACTICAL WORK	81
1. Parasites of Deciduous Fruit Insects	82
2. Parasites of Forest Insects	93
3. Parasites of Cereal and Forage Crop Insects	98
4. Parasites of Vegetable Crop and Small Fruit Insects	101
5. Parasites of Tropical Field Crops	104
6. Parasites of Citrus Fruit Insects	105
7. Parasites of Greenhouse Insects	106
8. Parasites of Insects affecting Man and Domestic Animals	106
9. Investigations in the West Indies	109
10. Insects destructive to Noxious Plants	110
11. General Investigations	113
12. Summary of Projects submitted to the Laboratory	113
V. BIBLIOGRAPHY	117

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LIST OF ILLUSTRATIONS.

Plate		
I.	Farnham House Laboratory	Frontispiece.
		Facing page
II.	Diagnostic characters of entomophagous parasites	20
III.	1. Shipping Box with Mailing Case	34
	2. Cylindrical Glass Parasite Cage	34
IV.	1. Double Compartment Cage	35
	2. Standard Cage	35
V.	Plan of Grounds, Farnham House Laboratory	74
VI.	1. General Insectary	75
	2. Small Teak Insectaries	75
VII.	1. Oviposition Cage for Codling Moths	84
	2. Fiske Tray	84
VIII.	1. Rearing of *Aphelinus mali*	85
	2. Collection of *Sirex* Parasites	85

I. INTRODUCTION.

THE present report contains a general account of the work on Biological Control carried on at Farnham House Laboratory, which, having regard to its field of activity, resources and programme, can fairly claim to be the most important centre for work of this type now existing in the Empire.

A few words of explanation in regard to the rather unusual form of the report are perhaps necessary. Since it is the first published report it has been designed with the object of giving a comprehensive idea of the policy, organisation, resources, and practical efforts of the Laboratory. The second part is devoted to a general account of the problems encountered in operations in biological control with special reference to the organisation and conduct of practical work. A certain number of purely theoretical considerations have been included because of their value in indicating lines of research in the Laboratory and in the field ; but the great majority of the statements and suggestions are the fruit of some twenty years' experience in work in this field and have been repeatedly tested in practice. An attempt has been made to arrange them so that they constitute, as it were, a rough sketch of the technique of this branch of economic entomology. So far as the writer is aware no account of this kind has yet been published.

The third part of the report deals with the history, organisation, and equipment of the Laboratory, in order to show what resources it possesses to cope with the problems encountered in practical work. The fourth part gives a summary of the results obtained up to the present date together with a list of the projects which have been submitted to the Laboratory. A bibliography, including the papers most useful to workers in this field, has been appended.

The writer wishes to express his sincere appreciation of the encouragement and support received during the course of the work from Dr. G. A. K. Marshall, Director of the Bureau, Dr. S. A. Neave, Assistant Director, and the Staff of the Laboratory, all of whom have contributed in various ways to the progress of the work and assisted in the production of this report.

As has been stated elsewhere, the foundation of the Laboratory was made possible by grants from the Empire Marketing Board, and the officials of that Board have been most helpful and sympathetic in every way. Further we are indebted to them for the publication of this account of the work.

II. THE PRINCIPLES AND ORGANISATION OF WORK IN BIOLOGICAL CONTROL.

In this section it is proposed to give a general account of the way in which work on biological control is planned and executed at the Laboratory, in order to give some idea of the principles underlying it and of the technique used in practical work. This outline is divided into sections which follow the entomologist, so to speak, step by step in the investigations and practical efforts which he is ordinarily obliged to make in undertaking work on the biological control of the average insect pest. To those acquainted with the subject, some of the remarks and recommendations may seem superfluous. However, experience shows that they are sometimes necessary, and they are included for the sake of making the account as complete as possible.

1. *The Principles of Biological Control.*

The practice of biological control owes its origin to the fact that a great many injurious insects and plants are attacked by parasitic and predacious species, belonging to the same group. These beneficial insects play an important part in the natural control of many destructive forms. Furthermore, many plants injurious to agriculture and forestry have also their insect enemies, which seem in some cases to exert an important effect in limiting their increase and dispersion. When insect pests are accidentally transported to new countries, leaving their habitual parasites and predators behind, they frequently become extremely numerous and cause immense damage ; for as experience has repeatedly shown, they are generally attacked to only a negligible extent by the beneficial species existing in their new homes. Of the 183 worst insect pests existing in North America almost half have been introduced from foreign countries, and of these, a large proportion came in from Europe (Smith '29). The Hessian Fly alone destroys each year a proportion of the wheat crop, valued at approximately £800,000. The control of the Gipsy Moth, accidentally introduced into America about 60 years ago, costs the United States about £50,000 per annum. The European Corn Borer, which reached America about 15 years ago, has done so much damage that appropriations of from £50,000 to £150,000 are being made annually in order to fight it, and in 1927 the sum of £2,000,000 was expended in order to arrest its spread. The insect now constitutes a

serious problem for Canada ; in 1925, an area of at least 400 square miles of excellent maize country in Ontario suffered a complete loss owing to its ravages. The Oriental Peach Moth, the Japanese Beetle and the Mediterranean Fruit Fly are also extremely serious(*).

In former times no regulations designed to prevent the importation of insect and plant pests existed, but as transport was very slow and no means of preserving foodstuffs existed, opportunities for the migration of injurious insects were not really very numerous. The modern development of rapid transport and of methods of food preservation, particularly cold storage, allows of the exchange of fresh or living food products between far distant parts. This development of a world trade has permitted and fostered cosmopolitan tastes and requirements, which in turn further stimulate commerce between the various points of the globe.

Now these modern developments of trade and transport permit injurious organisms to traverse, with relative ease, geographical barriers that formerly constituted impassable obstacles, under conditions which are exactly what they require. The rapid methods of locomotion bring them to new food supplies before the material in which they are being carried is exhausted, the cold storage facilities enable them to make the journey in a dormant state so as to issue in an active and healthy condition in their new home.

The increase in the development of world trade has thus, as a necessary consequence, caused an increase in the rapidity of the dispersion of pests. The more we foster trade within the Empire, the more opportunity we give to the injurious insects and plants to move from one part of the Empire to another. It is thus safe to predict that unless special measures are taken to prevent it, losses resulting from the introduction of pests from other regions will increase from year to year in all parts of the Empire. Strict laws concerning the inspection and quarantine of imported materials, if enforced by sufficiently large and competent technical services, will do much to arrest the movement, but they will never check it completely. Several of the most injurious insects existing in the United States were introduced in recent years in spite of the inspection services.

(*) The sums which the United States Government has been obliged to expend to date in order to combat the Gipsy Moth, the European Corn Borer, the Japanese Beetle, the Mexican Bean Beetle, and the Oriental Peach Moth amount in the aggregate to over £12,000,000.

Once an injurious animal or plant is well established, it can seldom be exterminated. Measures designed to reduce as far as possible the damage which it occasions must, therefore, be adopted. Methods of mechanical control, such as spraying, fumigation, and so on, will usually reduce damage sufficiently to enable the farmer to produce a reasonably satisfactory crop ; but they increase the cost of production, and thus throw a heavy burden on either the producer or the consumer, and are, at best, mere palliatives. Such methods must, practically always, be repeated year after year. They do not bring the population level of the pests low enough to prevent a recurrence or even an increase of damage in the following year. In certain parts of the world, the amount of arsenic now used during the ordinary treatment against the Codling Moth in apples, is so great that the arsenical residue on the fruit at the time that it is gathered is dangerously large and has to be removed by special processes. There is some reason to suppose that the arsenical compounds washed down into the soil may, after a certain length of time, prove injurious to vegetation. Furthermore, in some cases at least, there is definite evidence that certain species of injurious insects are becoming immune to some of the poisonous substances ordinarily used, such as hydrocyanic acid gas and lime sulphur wash.

In view of the disadvantages of mechanical methods of control, entomologists are now attempting to utilise the parasitic and predacious enemies which attack injurious insects in nature. Many pests are attacked by one or more species of parasitic or predacious insects, which, in combination with other factors, often prevent them from multiplying excessively in their native homes. As we have already stated, it appears to be the escape from the parasites and predators, resulting from the transport of the injurious species to a new country, which is in many cases mainly responsible for its undue increase. Since organisms increase in geometrical progression, the survival in each generation of even two or three females above the number necessary to maintain the population at an even level, may produce in a relatively short time, disastrous results. For example, one female of a species with a three-fold increase per generation will have in the twentieth generation almost 8,000,000 descendants. This explains the phenomenal spread and catastrophic destructive power of certain introduced insects.

It is obvious that the attempt to keep pace with insect invasions of this type by the use of the mechanical methods of control may be extremely costly or even ruinous.

Under such circumstances, an attempt to deal with the pest by introducing its habitual parasites and predators is always advisable. Abundance of the host insect is one of the most important factors favouring their increase. Unless for some reason the new environment is unfavourable to them, they increase rapidly in numbers at the expense of the pest, and sometimes eliminate it as a practical factor in agriculture, or, at all events, reduce its power of multiplication so that its importance is very greatly lessened.

During the period between the colonisation of the parasite and the time when control is effected, it retards, but of course does not arrest completely the multiplication of a pest which is increasing and spreading. During this intermediate period mechanical measures of control must, therefore, be adopted. It does not appear, however, that these measures will increase the time required for control unless they eliminate a larger proportion of the parasite than of the pest.

The process of biological control is thus one which may require a considerable period of time, during which developments should be carefully followed, so that additional beneficial species can be introduced if this is necessary. This slight disadvantage is, however, altogether outweighed by the fact that in successful cases, what is practically permanent relief is obtained for an absolutely trifling cost. Once biological control is established and the beneficial insects introduced are distributed over the whole of the infested area, any outbreaks that may occur owing to conditions momentarily disadvantageous to the parasites, due either to their own action or to that of environmental factors, are ordinarily brought under control automatically owing to the increased facilities for the reproduction of the parasites produced by a more abundant host population.

The successes obtained with the method of biological control in relation to a number of serious insect pests have been so striking that all the important entomological services now include it in the programmes of investigations concerning introduced pests. The Hawaiian Sugar Planters' Association have for many years past employed a special staff of entomologists to deal with the insects of sugar cane along these lines, and recognise that biological control has, in fact, saved the Hawaiian sugar cane plantations from complete destruction. The United States Bureau of Entomology maintains special investigators in all parts of the world to study and collect the insect enemies of introduced pests. The funds allotted to the laboratory

dealing with the European phase of the Corn Borer work alone have amounted for several years past to about £5,000, and sums almost equally large are expended on many other projects. The total sum set aside each year by the United States Government for work on biological control exceeds £100,000. The State of California has an independent organisation for the purpose, enthusiastically supported by the horticulturists of the State, because of the practical help they receive from it. One of the important projects carried on by this organisation, under the capable direction of Professor H. S. Smith, is the breeding of the Cryptolaemus ladybird to control the citrophilus mealy-bug, an extremely dangerous insect which is bound to become of considerable importance to the British Empire. On this project alone the sum of £40,000 is expended annually; but the work is far cheaper than any known method of mechanical control and is a complete success. The Canadian Entomological Service maintains at Belleville, Ontario, a parasite laboratory, mainly concerned with the Corn Borer and Peach Moth problems, but which will certainly extend its activities in the future, especially if we are able to provide it with the material it requires. Parasites introduced from England against a very serious insect of larch, the Larch Sawfly, have proved highly successful, and according to the Dominion Forest Entomologist, are rapidly bringing this pest under control. The Cawthron Institute in New Zealand, and, more particularly, the new Federal Entomological Service of Australia, have made experiments in biological control the most important department in their work, while efforts along the same line are being made in South Africa, India, and a large number of the British Colonies and Dependencies, as well as in foreign countries.

Within the British Empire, work on biological control has not, until quite recently, been as actively pursued as in some other countries, principally because of the inadequate character of the entomological services, due in turn to the insufficient appreciation of the tremendous losses incurred through the attacks of injurious insects. At present, however, attempts to introduce and utilise beneficial insects are becoming rapidly more numerous in all parts of the Empire. The effort to bring injurious plants under control by the use of phytophagous insects, initiated in Hawaii by Perkins and Koebele against Lantana, and in Australia against the Prickly Pear, is now being carried out on a more comprehensive scale in Australia and New Zealand, than in any other part of the world.

The use of the parasitic and predacious enemies of insect and plant pests constitutes, of course, as has already been pointed out, merely one of the methods of economic entomology. To describe it as a method destined in the near or even distant future to replace all other methods is quite unjustifiable. There are many cases in which it is inapplicable, either because the pests to be combated have no specific natural enemies, or because those which do attack them are of no practical importance, or, finally, because, though their work is sometimes effective, there is at present no way in which they can be utilised in practical work. Nevertheless, in spite of the fact that the application of the method of biological control is limited, the practical achievements in this field are economically of great importance,* and its possibilities are as yet far from being exhausted.

2. *Preparatory Work.*

The first step the entomologist must take when asked to utilise the methods of biological control in order to prevent damage by any pest is to diagnose accurately the cause of injury. Unless the plant or insect which is the cause of the damage has been accurately identified, it is impossible to find in the vast mass of entomological literature which now exists, the information which previous workers on the subject have accumulated. The first essential for the economic entomologist is thus the opportunity to consult with experienced systematists, having access to adequate collections and well stocked libraries. The inability of the authorities to appreciate this fundamental fact has rendered the task of the economic entomologist everywhere difficult, and has most seriously impeded the progress of the practical work in control.

When the injurious insect has been identified, the next step is to consult the works of other entomologists who have dealt with the subject. This is in itself an extremely difficult task. The literature on economic entomology is now enormous and the information in regard to important pests is scattered through a great mass of papers published in all parts of the world. If the entomologist has not at his disposal a fairly complete reference library, it is extremely difficult for him to collect, read and digest all the published works dealing with his subject. The fundamental necessities in work on

* One of the most remarkable successes in recent years is the elimination of the Coconut Moth by Dr. J. D. Tothill and his associates in the Fiji Islands. A detailed account of this work is now in course of publication.

biological control as in all other phases of economic entomology are thus facility of identification and a summary of the current literature. In order to meet these needs the Imperial Bureau of Entomology was founded in 1912, having as its principal function the collection and co-ordination of all information bearing on injurious or useful insects, and the organisation of a system for securing the authoritative identification, with reasonable promptitude, of all insects of economic importance, submitted by officials connected with Departments of Agriculture or Public Health throughout the Empire, together with the preparation of a card index to the whole literature of the subject and the compilation of a journal, intended to give an up-to-date epitome of the current literature. The Imperial Bureau of Entomology is now so well known, and its identification service and its Review of Applied Entomology so familiar to entomologists, that they need no description. They have, however, been mentioned in order to bring out the fact that the work on biological control inaugurated at the Laboratory, is being carried on within an organisation already possessing comprehensive resources in regard to identification and a bibliographical service unequalled anywhere in the world, which renders possible an extremely rapid and efficient survey of any problem.

Through the courtesy of Dr. S. A. Neave, Assistant Director of the Bureau, the Laboratory has obtained the part time service of Miss R. N. Davenport, an expert bibliographer, who has prepared in the form of a card catalogue, a complete bibliography of all the projects undertaken by the Laboratory. This bibliography is based, for the most part, on the Review of Applied Entomology and enormously facilitates the preliminary work on our problems.

As the work of the Laboratory is, at present, almost exclusively in the field of biological control, the information regarding any insect pest which is most important to us, is, of course, that which concerns its parasites and predators. In order that this information may be obtained in any given case, without delay, the bibliographer, has prepared a card catalogue of the parasites and predators of all the insects mentioned in the Review of Applied Entomology as having natural enemies, and cross-reference cards giving the recorded hosts of all the parasitic and predacious species mentioned, and the titles of the articles in which the records are given. This catalogue now includes over 10,000 cards, though it is not yet by any means completed. A list of parasitic Nematodes has recently been included in it.

A list of all the projects submitted to the Laboratory by the entomologists of the Empire is kept on cards in a special file, on which the most important information concerning the species studied is tabulated. As soon as it has been decided to take up the investigation of one of these projects, the member of the staff detailed to the work consults the bibliography of the species and prepares a digest of the most important information, with special regard to the distribution and relative abundance of the species in various parts of its range. He then draws up from the Host and Parasite Catalogue a list of the parasites and predators recorded for the pest, making a special note of any point likely to be useful in the collection of parasitised material. A careful summary of these data is made and copies supplied to the field agents of the Laboratory for their information and guidance.

3. *The Preliminary Field Survey.*

When the data mentioned in the preceding paragraph have been gathered together they very often give a very good general idea of the main facts concerning the biological control of the injurious species. However, our information in regard to the parasites and predators of most injurious insects is still so incomplete, and our knowledge of the possibilities of the method so vague and uncertain that we can seldom make a decision in any given case without a careful investigation. As is well known, the published lists of the parasites and predators of injurious insects contain a great deal of erroneous information, owing to the fact that proper precautions are not taken in determining the relations between the parasitic and predacious species and the form they are supposed to attack. On the other hand, the natural enemies of a great many injurious species are still practically unknown even in Europe. For example, in 1919, only a single parasite, and that one wrongly determined, was known from the European Corn Borer. A careful investigation showed, however, that over twenty parasites belonging to several groups attack this pest. For this reason it is almost always necessary to make a careful field survey of the parasitic and predacious fauna of any injurious insect. In planning this survey it must be remembered that the parasites and predators attacking a pest very often differ in different parts of its range. Sometimes this variation depends on the fact that in different parts of the area in which it exists, it feeds on host plants belonging to different species. In other cases, although the host plant remains the same, the parasitic and predacious fauna

differ in composition in different bio-climatic regions. Furthermore, even when the same species of parasites attack the same pest in several different regions, it may happen that one of them is consistently abundant in one region and consistently rare in another. It follows that even when we are dealing with a single species of insect it is impossible to study and collect its parasites and predators in a single one of the districts it inhabits, while if the parasites and predators of a large number of species have to be investigated, the examination of a great number of different areas is absolutely essential.

It is obviously impossible for the staff of a small laboratory to carry out exploratory work of this kind. The field investigator must be able to move from part to part about the country with considerable rapidity in order to cover as much ground as possible during the period when the material containing the parasites or predators is available. It is not practicable for him to carry about with him the apparatus and equipment necessary for dealing adequately with the material he collects. On the other hand, the members of the laboratory staff cannot possibly suffice for the work they have to do if they are obliged to spend any large part of their time in the field. In order to work efficiently a parasite laboratory must, therefore, have a staff divided into a body of workers who remain at headquarters and a body of field investigators or scouts. In the opinion of the present writer the possession of an efficient field staff is absolutely essential for success in work of this kind.

With very few exceptions, as has already been pointed out, we know very little about the parasites and predators of even the major pests and hardly anything about their distribution in relation to their hosts, and in any event the precise manner in which the parasitic and predacious fauna of a given pest varies in composition in relation to habitat is usually unknown. It is, therefore, impossible to lay down any rules for the organisation of the field work equally suitable for all projects. However, as in all other aspects of the work, it seems, on the whole, better to organise investigations on some rational principle, even though this may be inadequate in certain cases, than to proceed simply by empirical or hit-or-miss methods. An effort is, therefore, being made to sub-divide the European area in which most of the work is done into the principal bio-climatic zones, differing in climatic, agricultural, and other features. It is hoped that eventually it will be possible to establish an agent of the Laboratory in a sub-station in each of these areas. The staffs of sub-stations working

continuously in a relatively restricted field in a given country rapidly acquire a very thorough knowledge of local conditions and customs, and through their acquaintance with the inhabitants of the district are able to carry out a survey of any kind with great rapidity and accuracy.

The first effort of the present Superintendent was, therefore, to bring together the nucleus of a field service. It has not, of course, been possible up to the present, because of the relatively limited resources of the Laboratory, to cover even in Europe, anything but a small proportion of the area in which collectors should be located. We have now, however, three field agents ; one located in England, a second in Northern France, and a third in the Mediterranean coastal regions.

To map out the bio-climatic areas, even very roughly, is not by any means an easy matter. Most papers on bio-geography, even in Europe, are either much too broad in scope to be of any use in work of this kind, or else treat of areas which are very limited in extent. No satisfactory treatise on the bio-climatic areas of Europe apparently exists. The entomologist is, therefore, obliged to utilise the information obtained from topographical maps, rainfall maps, and temperature charts, and draw up a plan of survey based upon the data given by these maps, and the available information concerning the distribution of the host plant of the species on which he is working.

The system of installing special agents in each locality to be investigated may appear at first sight to involve unnecessary expense, which could be avoided by obtaining the co-operation of scientific individuals or organisations in the various parts of the world. The fact is, however, that efforts to carry on any prolonged and difficult investigation in this way are very seldom successful, not because the average scientist is unresponsive to requests for assistance, or fails to appreciate the interest or importance of the problem in which he is asked to co-operate, but simply because he cannot find time from his own duties to undertake the detailed investigations which are necessary. Furthermore, if the data collected from various regions are to be of any value they must be gathered according to some definite and uniform plan, and it is very difficult to impose any plan of this kind upon individuals who give their services freely, and whom the organiser of the work is consequently not free to criticise. Much useful information can often be obtained from scientific workers or

agricultural officials in the region studied, but unless they can actually be employed by the organisation it is impossible to rely upon them for any continuous and detailed study or collections. A field organisation under the control of the staff at headquarters is therefore necessary.

After it has been decided in what region the preliminary collections shall be made, the next step is to pick out points within the region likely to give a representative idea of conditions as a whole. It is, of course, impossible to decide in advance what localities are really most suitable for the work. The best practical rule is to select points which are at once accessible and significant, in that they represent, within the bioclimatic area studied, a number of different sub-types, characterised by topographical, agricultural, or other features. In order that work of this type may be planned to the best advantage, it is desirable to have at headquarters a collection of the most important works dealing with the climatic, agricultural, and biological characters of the principal areas in which the work is to be done. An effort is being made to gather together a library of this kind. Another very important part of the equipment necessary for the work is a collection of detailed and accurate maps, including a series on as large a scale as possible, for the regions in which collections are made. One set of these maps is kept at headquarters, the other in the possession of the agents in the field, who send with their material, indications as to the precise points at which their collections are made. In this way it is possible, as the work progresses, to obtain exact information as to the ecological conditions in each locality, which can then be correlated with the data obtained from the examination of the material.

The work of the field agent will not give results corresponding to the efforts expended, unless reasonably full and accurate data concerning the conditions under which the material was collected are obtained. In order to ensure this the most convenient method is to supply the agent with printed forms, on which the data desired by the entomologists in charge of the work are indicated and which can be filled in at the time the collections are made. The printed forms are bound up for convenience in booklets provided with a heavy cardboard cover, and filed as they are received.

The equipment of the field agent need not be very elaborate since the detailed investigation of the material sent in is carried on at headquarters. He is, however, provided with a field kit consisting of

a hand lens or folding microscope, and the usual entomological equipment, together with a supply of mailing boxes. The design of the mailing boxes is of considerable importance. The type used at the Laboratory (Pl. III, Fig. 1) is the one originally developed at the Corn Borer Laboratory of the United States Department of Agriculture, for the shipment of the larvæ of the Corn Borer. It is a cylindrical brass box, with large openings covered by copper gauze in the sides, so as to give a certain amount of ventilation. These boxes are sent in heavy cardboard postal boxes of the same size, with a cover attached by tapes. They are not too heavy to send through the mails and are yet strong enough to resist injury. They are therefore used in all cases where the material collected is not too bulky to be sent in this way.

As is well known, the various stages of insects and plants are attacked by different pests or natural enemies. An effort is therefore made to obtain in the preliminary collections material of each stage. This necessitates making one round of visits about the end of the period of oviposition, and another about the middle of the period of pupation. It is obvious that when several projects are being carried out by the same agent his itinerary and the organisation of his work must be very carefully planned.

It is hardly necessary to give any details as to the precise methods of collection, since these differ in regard to every insect studied. The regions in which collections are made are for the most part at a relatively short distance from headquarters, so that the collections are posted on the same day that they are made. There is thus usually little mortality during transport. The field agent is, of course, notified of any mistakes made during the process of collecting and packing as soon as the material has been examined.

4. *Examination of the Material.*

It is an unfortunate fact that the technique employed by many entomologists in studying the parasites and predators of insect pests in the past has been in some ways seriously defective. A method very frequently used is to take the material and place it without any careful examination in large cages, where it is supplied with food, after which the adult pests and parasites which emerge from it are collected from time to time. This procedure has been in the past, and still is, the cause of a great many serious errors, which could

easily have been avoided. The methods employed during this phase of the work must be such as to give absolutely accurate and definite information as to the relation of any parasites or predators obtained to the host which is being studied ; or, in other words, they must be such as to demonstrate beyond any possibility of doubt that the parasites or predators obtained have actually been feeding upon the insect with which they are associated in the rearing cages.

The first step in the examination of the collection is, therefore, to pick it over very carefully, examining, if possible, every individual specimen, in order to make certain that nothing but the species studied is being introduced into the rearing cages. If two or more allied genera or species are being collected these should, as far as possible, be separated before the material is studied. In many cases the preliminary collections contain cocoons, larvæ or puparia of parasites, and larvæ or adults of predators, considered by the field agent to be associated with the pest under consideration. A very careful investigation must be made before it can be decided that these insects are really parasitic or predacious on the pest studied. In the case of larvæ, cocoons, or puparia of parasitic insects, a careful search must be made for the remains of the host, which can generally be found in close proximity to the parasite at the time of collection. Any remains of this kind, such as larval skins or pupal shells, are prepared and examined microscopically, and compared with known specimens of the host insect in the same stage. Unless this precaution is taken, very serious mistakes can easily be made. Thus, during the work on the parasites of the Corn Borer, undertaken by the writer, a considerable number of cocoons of Tryphonine Ichneumonids were found in the tunnels of the hibernating caterpillars, and these were at first considered to be parasitic on the Corn Borer, but later investigations showed that they really had emerged from the larvæ of certain sawflies which entered the tunnels of the Lepidopteron in order to pupate. Their true host relations were eventually determined by an examination of the empty host skins found in close proximity to the cocoons.

Furthermore, it must be remembered that the parasites or predators which issue from cocoons or puparia associated with the host, do not always belong to the species which produce the cocoons or puparia in question, but may be secondary parasites, or parasites which are for the most part primary but become secondary parasites under certain special circumstances. For this reason, unless the

status of a parasite is already definitely known, it is necessary to open the cocoons from which it emerges and examine them carefully to see whether they contain the remains of another parasite on which the individual reared may have been feeding. When the host studied is one whose larvæ mine or bore within the tissues of plants, shrubs or trees, these should, if possible, be transferred to new and uninfected material, or should be isolated in portions of the food plant, which have been examined with care, and are known to be free from infection by any other species. It is very often useful to collect and rear hosts and parasites from large quantities of material, which has not been examined in this way, in order to obtain specimens for study and breeding work, but collections of this kind should not be relied upon for accurate data.

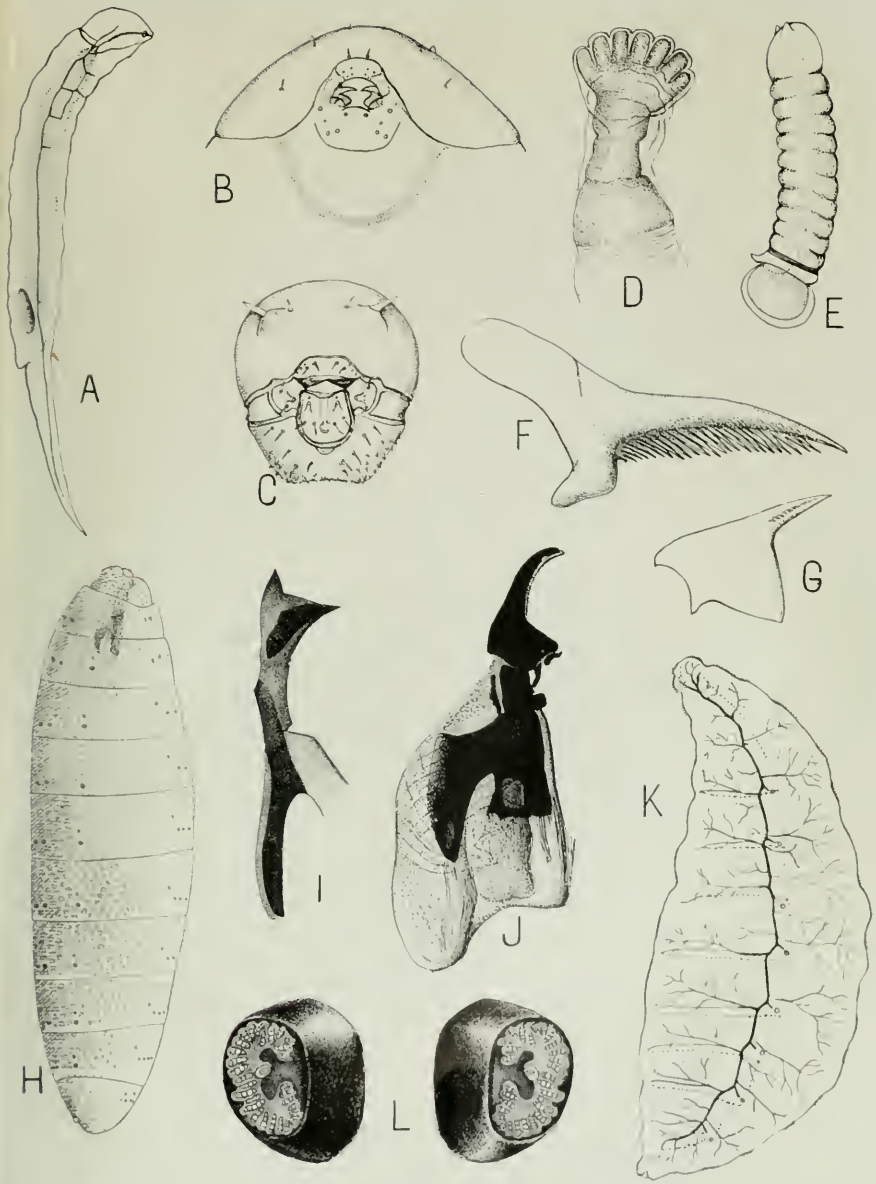
In view of the difficulty of identifying parasites and predators during the early stages it is usually necessary to continue the rearing work until the natural enemies are obtained in the adult condition, in order to identify them. Nevertheless, in a great many cases much valuable information can be obtained by careful dissections of the material collected. From such dissections it is usually possible to determine, with a very fair approximation, the number of species of parasites and the groups to which they belong. In this way also, the percentage of parasitism by the various species of parasites occurring in the different regions in which collections have been made, can be determined with accuracy quite sufficient for practical purposes. Before the dissections are made the material is, if possible, separated according to the various stages of development, and these are examined separately to obtain some idea of the time at which the parasitic attack takes place, and the time at which the parasite larvæ kill and emerge from their host. Without such information collections may be made before the parasitic attack has begun, or after the parasites have left the host.

As has already been stated, it is very difficult to identify the larvæ and pupæ of parasitic insects with accuracy, partly because, up to the present, they have been relatively little studied. The following key will, however, give some idea of the main characteristics of some of the principal groups. (See Plate II).

Group I.—Larvæ legless, maggot like, circular in section, but tapering from the posterior to the anterior extremity ; three thoracic

Plate II.

A. Primary larva of an Ichneumonid showing well-developed head, conical tail and longitudinal thoracic tracheal commissure (after Seurat) : B. Head of Chalcid larva (Mormoniella brevicornis, *after Parker), ventral aspect showing absence of differentiation between maxillary and labial areas. C. Head of Braconid larva* (Microbracon brevicornis, *after Genieys) showing differentiation of maxillary and labial areas. D. Anterior spiracle of Tachinid larva Stage III* (Miltogramma punctatum, *after Thompson) showing digitate form. E. Primary larva of Braconid* (Apanteles melanoscelus, *after Crossman), showing globular tail : F. Mandible of Braconid larva* (Microdus dimidiator, *after Silvestri), showing teeth. G. Mandible of Ichneumonid larva* (Pimpla nucum *after Silvestri), showing absence of teeth : H. Primary larva of Tachinid* (Epalpus signifera, *after Thompson) showing pseudocephalon and posterior spiracles I. Mouth-hook of primary Tachinid larva* (Rhacodineura antiqua, *after Thompson) : J. Mouth-hook of Stage III Tachinid larva* (Miltogramma punctatum, *after Thompson) K. Braconid larva* (Microbracon brevicornis, *after Genieys), full-grown, showing tracheal system with circular spiracles and absence of longitudinal thoracic tracheal commissure. L. Posterior spiracles, Stage III Tachinid larva* (Rhacodineura antiqua, *after Thompson*). *Drawings by M C Thompson*).



Diagnostic Characters of Entomophagous Parasites.

[To face page 20.

and eight abdominal segments ; without a definite head capsule, the cephalic region greatly reduced, unpigmented, retractile, bearing only some microscopic sensoria ; mouth parts consisting of a single median hook or a pair of parallel non-opposable lateral hooks having a dorso-ventral movement in the median plane and which are posteriorly articulated to or fused with a highly chitinised and pigmented skeletal structure in the wall of the pharynx, which is U-shaped in section and provided with muscles so as to form a pharyngeal pump ; tracheal system apneustic, metapneustic, or amphipneustic ; the anterior spiracles, when present, usually digitate and situated near the posterior border of the first segment, the posterior spiracles usually much larger than the anterior spiracles, situated side by side on the flattened posterior face of the last segment ; cuticle unpigmented, excepting in the first stage larvæ of certain groups, but bands of pigmented spines usually present : almost always three larval stages : usually contracting a respiratory relation with the external air ; parasitic forms endophagous ; pupa formed within the hardened larval skin, constituting a puparium.

Diptera Cyclorrhapha (*Pipunculidae, Phoridae, Muscidae sens. lat.*).

Group II.—Larvæ legless, but not usually maggot like, cylindrical in form though sometimes with a spherical or conical tail ; three thoracic and ten abdominal segments in most forms, though various exceptions exist ; mouthparts consisting of a pair of opposable mandibles, articulating with the tentorium at the sides of the mouth opening ; maxillary and labial appendages sometimes present or represented by definitely circumscribed sensorial areas, but often absent ; with a definite head-capsule, often pigmented, the cephalic region not notably reduced, often large, not retractile, bearing microscopic sensoria or setae ; pharyngeal wall without a definite chitinised skeleton ; tracheal system apneustic, metapneustic, or peripneustic, with spiracles approximately equal in size and similar in form ; cuticle unpigmented excepting in the early stages of certain Chalcids (Perilampidae, Eucharidae) ; setae often present but usually feebly or not pigmented ; bands of highly pigmented spines not usually present ; four or five larval stages ; usually lying freely within the body-cavity of the host without contracting a respiratory relation with the external air ; parasitic forms ectophagous or endophagous.

Hymenoptera Parasitica.

A. Maxillary and labial appendages present or sensoria arranged in definitely circumscribed maxillary and labial areas, at least in the later stages of development ; cocoons usually formed.

(*a*) An accessory longitudinal tracheal commissure lying in the thoracic segments ventra of the tracheal trunk, toward the ventral part of the body ; tracheal system apneustic or peripneustic ; nine pairs of functional spiracles usually present in the later stages ; a conical tail often present in the endophagous species ; mandibles usually simple ; three thoracic and ten abdominal segments ; ectophagous or endophagous ; usually solitary or feebly gregarious.

Ichneumonidae.

(*b*) No accessory longitudinal commissure ; tracheal system apneustic or peripneustic ; nine pairs of spiracles in the later stages ; a globular tail or caudal vesicle often present in the endophagous forms though a trifurcate tail is sometimes present ; mandibles sometimes simple but often toothed or pectinate ; three thoracic and ten abdominal segments ; ectophagous or endophagous ; often gregarious, seldom solitary.

Braconidae.

B. Maxillary and labial areas not differentiated ; the sensoria below the mouth opening not grouped on definitely circumscribed regions ; mandibles usually simple, no accessory longitudinal tracheal commissure in the thorax ; apneustic, metapneustic or peripneustic, spiracles variable in number and arrangement ; endophagous forms sometimes with a tail ; cuticle usually colourless, but highly pigmented in the first stage larvæ of the Eucharidae and Perilampidae ; setae present or absent ; three thoracic and ten abdominal segments usually present ; ectophagous or endophagous ; usually gregarious, seldom solitary ; except in the case of certain parasites of Coccids, or the eggs of Lepidoptera, not contracting a respiratory relation with the atmospheric air ; cocoons seldom formed.

Chalcididae.

This key will help to identify the parasites most commonly encountered in dissections, but does not include the members of several minor or little known groups. Of these, the most important are the heterogeneous family Proctotrypidae, including a number of parasites of economic insects such as leaf-hoppers, gall-gnats, wireworms, etc., and the parasitic forms of the family Cynipidae, of which

a number are parasitic in the larvæ of root-maggots, blow-flies, etc. Extensive further researches are necessary before a summary of the larval characters of these groups can be given.

The most thorough treatment of the larvæ of any group of the parasites of insects is that published in 1924 by H. L. Parker on the larvæ of the Chalcididae. A general account of the larval biology of the Ichneumonidae, with numerous figures, was given by Cushman in 1926; while valuable descriptions of Braconid larvæ have been published by Keilin, de la Baume Pluvinel, Crossman, Genieys, and others. Proctotrypid larvæ have been described by Ayers, Marchal, Keilin and Thompson, Haviland and Eastham, and Cynipids by Jaìnes, Keilin and Haviland. Descriptions of numerous species of Tachinid larvæ will be found in the papers by Green, Nielsen and Thompson listed in the bibliography.

An effort is being made to gather together at the Laboratory, for the reference of the staff, as complete a collection as possible of the larval forms of the various parasitic groups, together with a complete set of all the existing papers dealing with the subject. The collection of Tachinid larvæ includes over 100 species of this group belonging mostly to the European fauna.

An important point concerning the examination of the material collected concerns the keeping of records. An effort has been made to devise a system of notes as simple and practical as possible, but capable of extension in the case of projects requiring long and extensive investigations. The note cards are kept in loose-leaf notebooks and are filed at the conclusion of an investigation. Each lot of material received from the field and each experiment started on the subject is given a separate number or sub-number, and all material placed in rearing cages, or preserved in any way is labelled with this number. At the conclusion of each experiment the data is filed under its respective number, and under the name of the species concerned. Provision is made on the note slips for the utilisation of a numerical system for the classification of data, analogous to that proposed some years ago by Hinds and Bishopp for the work on the Cotton Boll Weevil.

From the preliminary collections and dissections it is generally possible to select one or more of the best localities in which to make collections on a large scale. Before this work is begun, it is, of course, necessary to investigate more fully the biology and inter-relations of the various species concerned. In order that this work may be pushed

forward as rapidly as possible, it is sometimes desirable to accelerate the development of the parasites. A portion of the material collected is, therefore, placed in an incubator acting at a constant and relatively high temperature, and in this way the adults of the parasite or predator can often be obtained many months before they would normally emerge in the field, and any information contained in the literature in regard to their biology can be readily secured. This sometimes makes it possible to carry out the whole work from the preliminary collections to the large scale shipment within a single year.

5. *The Choice of the Species to be utilised.*

It is now well known that the great majority of pests are attacked by several species of parasites and predators, which affect them at different stages of development. The various species differ in habits and in relative efficiency, so it is necessary to devote some thought to the question of their relative usefulness, or, in other words, to the selection of species likely to be suitable for the control of the pest in the country into which it has been introduced. This subject has been carefully discussed by several entomologists. Trouvelot (1925) considers that the choice of parasites depends, in the first place, on the characteristics of the biology of the host insect. If the host is a species of which the population remains approximately constant from year to year, as in cases where energetic destructive measures are not periodically employed, the most valuable parasites will probably be those with markedly specific host relations, producing an abundance of offspring and having a developmental cycle more rapid than that of the host. Beneficial species of this type will thus be especially valuable against insects destructive to perennial cultures, such as fruit or ornamental trees, forests or grasslands.

If, on the contrary, the host is a species which fluctuates violently in numbers owing to remedial measures or the action of climatic factors, polyphagous parasites will be desirable, especially if the host becomes very rare at periodical intervals. Such parasites will be able to maintain themselves by breeding on the other hosts to which they are ordinarily attracted and will thus be already present in the field in appreciable numbers when the population of the host species begins to increase. A specific parasite would in such circumstances become extremely rare owing to the lack of hosts. Furthermore, while the food material of the host (or pest) is maintained by agriculture at a constant high level, so that it can increase rapidly and easily if other conditions are favourable, it will be some time before

the parasite can profit by this increase. It will recover less rapidly than the host because its food material has been reduced and rendered less accessible by the measures of control taken.

Among the parasites attacking only one particular stage of a pest with separate and distinct generations, such as the Gipsy Moth, the Codling Moth in the northern part of its range, the Pine Shoot Moth, etc., it seems best to select species of which the development synchronises with that of the host. If, in such a case the parasite passed through several additional generations in other hosts, it might not be able to maintain itself at a sufficiently high population level with regard to the pest against which it is being utilised, owing to the occasional absence or rarity of some of its intermediate hosts.

On the other hand, for beneficial insects attacking various stages of their hosts, and for those attacking hosts with overlapping generations, an asynchronous development is often desirable since it permits of very rapid multiplication.

Other important points to be considered are the parasitic activity of the species considered (effective reproductive rate, power of searching for the host, etc.), the tendency to superparasitism (deposition of an excessive number of eggs in a single host), tendency to hyperparasitism (habit of attacking other primary parasites), and, finally, the rapidity of dispersion of the beneficial species as compared to that of the host.

According to H. S. Smith (1919), the points of greatest importance concerning the habits of the available beneficial forms are the comparative reproductive capacity of the host and the available entomophagous insects ; the powers of locomotion both of the pests and their natural enemies, and the sequence of available entomophagous insects.

It does not appear, however, that up to the present the majority of entomologists engaged in practical work in biological control have made any serious effort to conform to these rules. The most important factor governing the conduct of most of the practical operations which have been undertaken has probably been of the financial order. Generally speaking if sufficient funds have been available, the practice of entomologists has been to import all the parasites and predators found attacking the pest without very much regard to their possible or probable interactions or their effect on species other than the pest considered. This, for example, has been the method followed in the long series of experiments in the Hawaiian

Islands, and in the operations carried out by the U.S. Bureau of Entomology in relation to the Gipsy Moth, the Brown Tail Moth, the Alfalfa Leaf Weevil, the European Corn Borer and the Japanese Beetle.

In recent years, as a result, more particularly, of the work of Pemberton, Willard and Bissell in Hawaii, there has grown up a belief that the practice of miscellaneous introductions may be, in some cases, very injurious. According to these authors certain of the parasites of the Mediterranean Fruit Fly introduced into Hawaii have interacted in such a way that a parasite able alone to control the host insect was greatly reduced in efficiency through the action of another parasite of much less value as a controlling agent. From this some entomologists have concluded that, in general, it is inadvisable to introduce parasites which may come into conflict in some way. Such conflict is, of course, a matter of fairly frequent occurrence. Furthermore, a few parasites are known,which, though they are of considerable importance in the role of primaries, may, on occasion, develop as hyperparasites of other species. The whole subject has recently been discussed in a detailed and comprehensive way by the well known American authority on biological control, H. S. Smith (1929), who maintains that it is probably never disadvantageous to introduce conflicting species no matter in what way the conflict may come about. He shows fairly conclusively that the data given by the Hawaiian authors really does not constitute a valid proof of their contention, and his treatment of the whole subject is in every way so far superior to that of the upholders of the opposite view, that the hypothesis of multiple introduction must be considered, at present, to hold the field.

It may, however, be shown mathematically that in certain special cases, during the period when both the host and the parasite are increasing, a parasite, which by itself is unable to overtake the host, may yet be able to check the increase of another parasite capable alone of exterminating the host. Certain results obtained by V. Volterra in his mathematical studies also seem to suggest that if a parasite and its host have reached a condition of equilibrium, the addition of a second parasite might produce perturbations from which the host would ultimately emerge at the same average level. It seems, therefore, that the whole subject merits further discussion, even from a theoretical standpoint. One point which may, however, be borne in mind, is that a successful introduction may be retarded but cannot be annulled. Once a parasite has

become established in a new country, it is impossible to exterminate it, and if any harmful effect does result it will continue for an indefinite period. It seems, therefore, in view of the complex way in which parasites act upon each other and upon their environment that it would be as well, on general grounds, to proceed with considerable prudence. It may be, as some maintain, that even when a host insect has reached a condition of stability a single species of parasite is unable to bring it under control in the economic sense, either because it is unable to attack the host over the whole area in which it exists, or else because the gradual rarefaction of the host population produced by the action of the parasite begins to interfere with the activity of the latter before it has reduced the host to a point below the level of economic damage. Again, the action of a parasite or predator is not usually equally intense over the whole area of distribution of the host, from which we may infer that a parasitic fauna, including several species, is generally likely to be necessary. Nevertheless, the most satisfactory method of ensuring the establishment of a parasitic or predacious fauna capable of producing the desired results, seems to be to introduce the parasitic or predacious species singly, and observe their progress and the effect which they exert upon the host when they have reached their maximum development, after which other species can, if necessary, be brought in with a definite knowledge of the needs of the situation. If there is the slightest risk of producing ill-effects which will endure until the end of the time, by the promiscuous and simultaneous introduction of all the available parasites and predators, this method may legitimately be rejected, even though some loss of time may thereby be entailed. The presence of a large number of species of natural enemies greatly complicates the task of the entomologist who is studying the effect of the introduction, and probably will not, in many cases, very greatly accelerate the process of control.

We therefore prefer, for the present, to introduce one species of natural enemy at a time, and to wait until this species has begun to exert its effect before proceeding further. This method of work is not only, on general grounds, justifiable but is also the most practicable procedure in the case of an institution like Farnham House Laboratory, where the amount of money available for any one project is distinctly limited. On the other hand, if only a single parasite is collected for export, it must be chosen with some care. The simplest and most satisfactory principle on which to make the collection is to choose the species which is the most efficient in the

region studied. If in two different parts of the area in which collections are made, there are two species equally efficient, the choice will fall on one from a region which is similar in its general characteristics to the one into which the parasite is to be introduced. There are, of course, difficult cases, as when an important parasite, primary in one species may be secondary in relation to some other important pest in the infested area. Such cases are dealt with as they arise.

The idea of parasite "efficiency" needs some explanation. As used in ordinary practical work, it generally designates the species which is most frequently found associated with the host and consistently destroys a large proportion of its population, this proportion being calculated, however, not in relation to the total number of offspring produced, but in relation to the population at the time of collection, i.e., the number of individuals in the developmental stage collected. Such values are, of course, not comparable either as between parasites attacking different stages in the same zone, or between parasites attacking the same stage in different zones or different seasons, because they do not indicate the fraction of the total population destroyed by the various species. This is serious enough, but what is more so is that they have relatively little value as indicators of the real significance of the parasites as controlling factors, because they give us no indication as to the fraction of the total population for the destruction of which they are indispensable, nor of its potential value as a controlling agent.*

On the other hand these figures do give us some idea as to the relative value of species attacking the same stage in the same zone and in the same season, and in view of the ease with which they can be obtained and the enormously greater difficulty of obtaining the true values, we are obliged, at present, to use them as rough indicators of parasite efficiency.

In view of the difficulty of predicting the behaviour of an organism after it enters an environment in which it has not previously been observed, the formulation and adoption of more complicated rules seems, at present, impossible.

* It appears from the studies of Volterra that if ε is the coefficient of decrease of the parasite in the absence of the host and γ the coefficient of its "parasitic activity" (ability to detect and attack the host), then the *average level* of the host population, and, consequently, the average level of economic damage, will depend on the value of the relation $\frac{\varepsilon}{\gamma}$, which could therefore be considered, from the economic standpoint, as the coefficient of parasitic efficiency.

6. *Large Scale Collection and Shipment.*

Although the introduction of the natural enemies of an introduced pest is now very generally practised, some considerable interval of time usually occurs between the moment when the pest is first observed and the moment in which the parasite is introduced. Furthermore, a considerable period usually elapses before an introduced pest is discovered. The data available on this subject seem to indicate that during the initial period following its introduction the pest usually spreads as it increases in such a way as to cover a very large area, in which it is present for a fairly long time in numbers so small that it escapes detection, after which it suddenly appears in a large number of points, where it rapidly becomes abundant.

Since the host insect is usually present in large numbers and distributed over a large area, it is obvious that whenever possible it is best to introduce a parasite or predator in as large numbers as possible at a number of points over the infested area. In this way we are more likely to secure the establishment of the beneficial species and the control of the pest within a reasonable time. The provision of parasitic or predacious species in large numbers thus constitutes a very important problem in work on biological control. The supply of a large number of individuals of a parasitic or predacious species can be arranged in two ways. The first is the breeding of the species from a small stock collected in the field; the second is the direct collection in its native home of large numbers of the parasite or predator. Each of these methods has its special advantages and disadvantages.

The advantages of the system of breeding the parasite in large numbers from a small stock is that it very greatly reduces the expense and effort necessary in the field. As we have already pointed out, the various parasites and predators which attack a pest are not uniformly distributed over the whole area in which it exists, and though they may be extremely abundant at certain points they may be very rare in others. The points in which they are abundant are, furthermore, not necessarily the same from year to year, so that in order to be sure of obtaining a large number by field collections in any given season a great deal of scouting work is sometimes necessary. All this can be avoided by breeding the species in the laboratory, and, as will be shown later, the cost of this operation, if properly organised is, in some cases, much less than that of making collections directly in the field. Another advantage of the method of breeding in the

laboratory is that the danger of introducing hyperparasites or other undesirable insects is practically eliminated, since all the material eventually introduced descends from a small number of specimens, which have been identified with certainty. Finally, in a good many cases the breeding work can be arranged in such a way that the adults are ready for liberation at the time when the hosts are in the condition most suitable for attack, whereas when the material is collected from the field it may be necessary to keep it in cold storage and ship it over long distances, so that it arrives at a time when the host has disappeared from the field.

The disadvantage of this method lies principally in the fact that it requires a very considerable amount of technical knowledge and equipment in order to carry it on successfully, and, at least at the beginning, a staff of trained assistants who must usually be kept on the pay-roll all the year round. Furthermore, there are certain parasites of which the host insects are extremely difficult to rear in captivity. The rearing of the parasite in large numbers depends, of course, on the rearing of the host. In really difficult cases the loss of material due to the mortality in rearing the host may very greatly increase the cost of production.

The advantages of the method of field collection on a large scale are, in the first place, that a rapid extension of the effort is possible with considerable ease because the method of collection can be readily taught to ordinary labourers, who might never acquire the necessary technical skill for carrying on the breeding work. Nothing but the most inexpensive and simple equipment is usually necessary. In the second place, the technical organisation necessary in order that secondary parasites and unwanted species of the other insects may be eliminated and the equipment required to ensure this, is much less elaborate than that which is needed for breeding work. In cases where it is desirable to introduce a number of species of parasites, several of these can usually be obtained at the same time, whereas several quite different methods and sets of equipment may be necessary if a number of species are to be bred in captivity. When species are collected directly in the field in large numbers, the establishment of the parasite can often be brought about immediately, whereas a long time may elapse before material can be obtained in sufficient quantities for the liberation of a large colony by breeding. Finally, after the work of rearing and liberation, which takes relatively a short time, the entomologist who is being supplied with material

collected in the field need give little further attention to the project, whereas continuous and often very time-consuming work is required for the breeding of the parasite.

The disadvantages of field collections are, in the first place, the greatly increased expense at the collection centre and in the transportation of the material collected, the danger of introducing hyperparasites or unwanted species of various kinds when the entomological staff at the receiving end is inadequate, and, finally, the difficulty of getting material to the point where it is to be liberated at the correct moment. This is especially serious in cases where material is transferred from the Northern to the Southern Hemisphere, or vice versa.

It will be clear from what has preceded that whether we are to choose the method of large field collections or that of breeding in the laboratory depends, on the one hand, upon the habits of the species concerned and, on the other, upon the nature of the organisations collecting and receiving the material. Certain species mate readily in captivity but can only with the greatest difficulty be induced to oviposit ; others oviposit freely when they are collected in the field, producing offspring of both sexes, but cannot be induced to mate, and, if reared in the laboratory from larvæ produce only male offspring. Others exhibit in captivity unfortunate habits which make it very difficult to rear them in large numbers ; for example, *Pimpla instigator*, when supplied with chrysalids, oviposits freely in them, but if it is allowed to do so, bites holes in them, even after oviposition, and drinks the blood of the chrysalids, so that both the host and the progeny of the parasite ultimately perish. In other cases the parasites are easy to handle, but the breeding work is rendered difficult by the problem of obtaining and rearing the host in large numbers. This is especially true in the case of insects like stem-borers, leaf-miners, or gall-makers, which live within the tissues of green and living plants. In such cases, as has already been mentioned, the loss through mortality and the expenditure of time and money necessary to collect host material, renders breeding work quite unprofitable.

The practice we have adopted is, therefore, to restrict our breeding work to species which reproduce freely in captivity and of which the hosts can be either bred or collected with ease and rapidity. In other cases we rely on large collections in the field. The existence of trained staffs in the laboratory and in the field enables us to change our method

of attack according to circumstances. Thus, the method of breeding on a large scale in the laboratory is used in the case of *Alysia manducator*, the parasite of the Sheep Blowfly, *Ascogaster carpocapsae* the parasite of the Codling Moth, and certain other parasites of this species, *Aphelinus mali*, the parasite of the Woolly Aphis, and *Blastothrix sericea*, the parasite of *Lecanium coryli*, of which the two latter species are bred in the insectaries. On the other hand, our consignments of the parasites of the Earwig, the Pear Slug, the Pine Shoot Moth, and the Sirex Wood Wasps, have been collected exclusively in the field.

The general subject of the breeding of the insect parasites and predators is much too difficult and technical to be treated within the compass of this paper, especially since the methods to be adopted vary a great deal in the case of different species. A few general suggestions may, however, be useful.

Not very many years ago the general impression among entomologists was that the best results could probably be obtained by providing the parasites with conditions resembling, as closely as possible, those existing in their natural environment. Parasites were, therefore, placed with the hosts in large cages, where they were able to fly about freely, and in which the hosts were feeding on plants arranged, as nearly as possible, in a natural manner. As work on breeding progressed, however, it was found that arrangements of this kind were, in many cases, not merely unnecessary but positively injurious. Thus, during the work in the Gipsy Moth Parasite Laboratory, the first attempts to breed the Dipterous parasites were made in large cages resembling outdoor insectaries, but it was found later that the loss through mortality before the parasite had reproduced in cages of this type was much greater than when various small cylindrical glass cages were used. Similarly, a number of years ago, when the writer first attempted to breed *Microbracon brevicornis*, the braconid parasite of the European Corn Borer, he thought it necessary to supply the parasite with live Corn Borer larvæ, lying in their tunnels in portions of the green Corn plant; but it was soon found that much better results could be obtained by placing the parasite in small tubes with unprotected larvæ of the Corn Borer, and a method of rearing the species along these lines on a very large scale was ultimately developed. Finally, in the breeding work on *Trichogramma*, the egg parasite of the Codling Moth and other Lepidoptera, this process of eliminating all but the conditions essential for life and reproduction in the most

efficient possible manner has been carried to its maximum. The parasite in question ordinarily attacks the egg of various butterflies and moths, which it finds on living plants in nature. As a result of a careful series of experiments for which Mr. S. Flanders, now of the University of California, is largely responsible, it has been found that this species can be bred in colossal numbers by utilising the eggs of certain insects attacking stored products, as for example, *Sitotroga cerealella* and *Ephestia kuehniella*. These moths are reared in cages of a special type on flour, rolled oats, or grain, and their eggs obtained in large numbers by an ingenious mechanical method. The eggs are then spread in fairly large numbers on sheets of paper in petri dishes with a number of the parasites, judged sufficient to produce practically complete parasitism of all the material supplied. In this way, by a careful adjustment of external conditions and a careful attention to the minute details of the process, the breeding work has been developed to such an extent that, under favourable conditions, a million parasites a day can be produced, though, as will be clear from the description, the conditions are very different from those the parasite meets in its natural habitat.

After some experience in this line of work, the writer has, indeed, become convinced that natural conditions are, in general, far less favourable to the development of large populations than those which can be supplied in the laboratory. By a careful study of the biology and physiology of the parasite and its host it is usually possible to determine, with a fair amount of precision, the conditions under which its development will proceed in the most rapid and normal manner. Conditions of this kind can then be supplied continuously, whereas in nature it is certain that they obtain only at infrequent intervals. For purposes of breeding, therefore, it seems that artificial conditions, in general, are likely to give more satisfactory results than in so-called natural conditions, and the practical results obtained up to the present support this theoretical conclusion.

As has already been stated, the process of breeding a parasite successfully in the laboratory depends essentially upon a careful study of its biology and habits. This does not mean that it is necessary in all cases to carry on a prolonged and detailed investigation into all phases of the physiology of the insect. If such work were necessary progress would be extremely slow. As a matter of fact, the number of points which need be investigated is relatively few. All that is necessary in regard to the phase concerned is to determine with

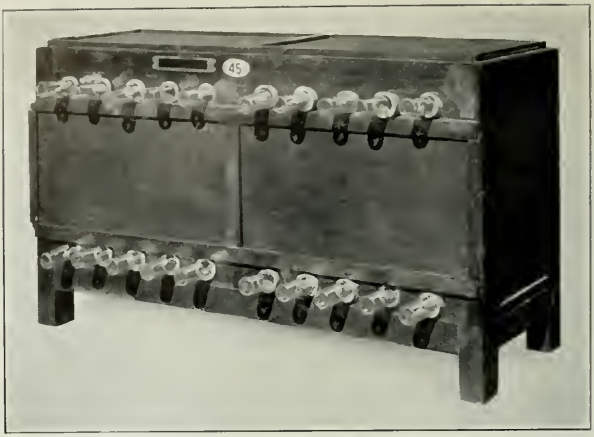
reasonable accuracy, under what conditions the reproductive process goes on with the greatest rapidity and in the most normal manner, so that large numbers of healthy offspring are produced.

In general, the receptacles in which the parasites are confined, should be large enough for them to move about comfortably, without being so spacious that they can take refuge in some corner at a considerable distance from the host or attain high speed in flight. In order to obtain satisfactory results, the parasite must, of course, be supplied with food. Failure to do this may very greatly reduce the length of life and the rate of reproduction. The nature of the food supplied varies somewhat in the cases of different species, but in practice the most useful types of food seem to be honey, or sugar-water, supplied in such a way that the danger of honey entangling the parasites is reduced to a minimum. A very useful food, first suggested by Dr. J. G. Myers of the Farnham House Laboratory, is raisins. In many cases very satisfactory results have been obtained by supplying the parasite simply with a number of raisins attached to a piece of cork, and a supply of water provided by a damp pad consisting of a piece of cloth covering a wad of cotton wool, dipping into a small, deep petri-dish, full of water. The raisins remain moist for a considerable period and certain parasites feed upon them with avidity.

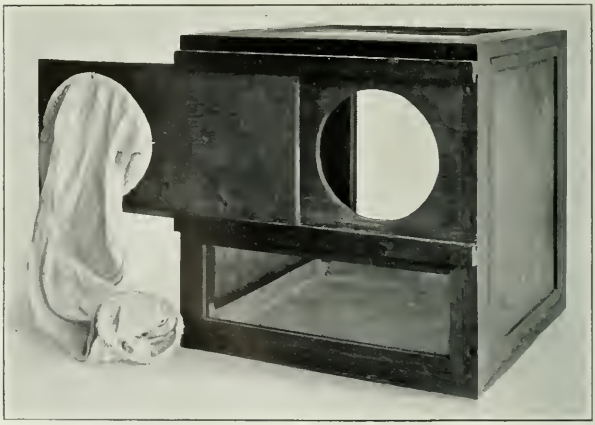
If they are properly cared for many parasites will, contrary to the general belief of many entomologists, live for long periods in the laboratory. Individuals of some species have been kept alive by the writer and other workers for periods of many months. Nevertheless, although most parasites are fairly easy to keep alive in captivity, it is not always an easy matter to induce them to mate and reproduce. The conditions governing mating in these insects are not by any means clearly understood at present. In some cases better results can be obtained if the males and females are kept separate for a considerable period and then placed in cages together, being separated after mating has occurred. In other cases even this method does not give satisfactory results. Thus, during the work on *Eulimneria crassifemur*, Thoms., Dr. H. L. Parker and the writer found it impossible to induce this species to mate in small cages, though it had been observed to do so as soon as the species was liberated for colonisation, in which case mating occurred immediately, in close proximity to the point where the liberation was made. After various

1. Shipping box (right) with its Mailing Case (left).

2 Cylindrical glass parasite cage, with water jar, raisins, and lump sugar.



1. Double compartment cage in teak with emergence tubes; front and top with sliding doors, behind which are glass panels.



2. Standard cage in teak with wire gauze sides, vita-glass front and top (removable) and sliding panel with sleeve in back.

To face page 35.]

artifices had been tried without success, some males and females were liberated in a large outdoor cage, to which the sun and air had free access, and mating occurred at once.

Certain other parasites can be induced to mate with a fair amount of ease, but cannot be induced to oviposit in captivity. In the case of some species studied by the writer, efforts continued over a period of many months have altogether failed to produce any satisfactory results. It appears that conditions of a very special kind, which it requires prolonged investigation to discover, may be necessary in order to secure reproduction. Thus, in working with the parasites of the Earwig, it was found that the most satisfactory results were obtained when the parasites, which belong to the group of the Tachinidae, was supplied with flowers of certain umbelliferous plants. Another point which must be borne in mind in the case of the Dipterous parasites is that a rather long period sometimes precedes oviposition, because development to the larval stage takes place in the uterus within the body of the mother, whereas in the case of the Hymenopterous parasite the egg is deposited in an undeveloped condition, and the parasite is sometimes ready to oviposit almost as soon as it has emerged from the pupal skin. Dipterous parasites, therefore, require a great deal of care, especially when they are active, and when kept in cages frequently reduce themselves to a very abnormal condition before they are ready to oviposit.

Furthermore, though it is sometimes fairly easy to induce a parasite to reproduce in captivity, it is not possible to rely upon its judgment for the proper distribution of its progeny. My experience, both in the field and in the laboratory, has shown fairly conclusively that the majority of parasites, if given the opportunity, will continue to deposit eggs and larvæ in individuals of the host until the number of parasites it contains far surpasses its capacity for supplying food, with the result that all of the progeny as well as the host perish prematurely. In order to avoid the consequences of reckless oviposition special arrangements are usually necessary. With some species all that is required is to remove the parasitised host and supply new ones at intervals, the length of which can be determined by a few careful experiments. In other cases the most satisfactory method is to allow the parasite to oviposit freely and distribute its eggs artificially upon a series of hosts in a suitable condition. This method was devised a number of years ago by the writer in rearing *Exeristes*

roborator, the parasite of the European Corn Borer. Experiments showed that this species oviposited freely in larvæ of the Corn Borer placed in sections of maize pith in which a small chamber had been hollowed out and which was covered with a thin sheet of pith or perforated paper. In order to prevent the host larva from escaping from the chamber, its head was crushed with a pair of forceps. Within the course of twenty-four hours the parasite stung the larva and deposited upon it a number of eggs much greater than it could possibly nourish. The eggs were, therefore, removed with a fine camel hair brush and placed one at a time upon caterpillars of the Corn Borer, which had been killed by a very short immersion in hot water. Although it was usually necessary to renew the caterpillars during the course of the development of the parasites, the method proved, on the whole, very satisfactory. When the supply of host larvæ became difficult to obtain an attempt was made to circumvent the difficulty by substituting the larvæ of a large ant (*Camponotus* sp.), which was fairly abundant in the region where the work was being carried on, and it was found that a fair proportion of the larvæ could be quite satisfactorily reared upon this host.

This method is, of course, only suitable in the case of parasites which deposit their eggs externally. It has not so far been found possible to utilise it with species which place their eggs within the body of the host. It is, however, quite suitable for species like some of the Dipterous parasites which deposit their eggs or larvæ in the vicinity of the host. Thus, the Tachinid, *Sturmia scutellata*, which is an important parasite of the Gipsy Moth, deposits its eggs on leaves, and when it has been induced to lay a few eggs, will usually continue to oviposit in captivity for a long time and will continue to deposit a great number of eggs on leaves in the absence of any host. These eggs can then be placed separately on leaves and fed to caterpillars. The same method was used by Altson in the case of one of the Dipterous parasites of the Earwig, and proved very successful. Similar methods can be adopted in the case of the parasitic flies of the same group which deposit their larvæ on leaves, and were utilised by Dr. Parker and the writer in rearing two of the Dipterous parasites of the Corn Borer, which have somewhat similar habits. In the case of the Dipterous parasites, it is possible to carry the artificial distributions of the progeny one step further. A number of years ago the writer carried out a few experiments in which larvæ of certain of the parasites of the Corn Borer, still undeposited, were removed from the uterus of

the mother, placed in saline, and then distributed by means of a small camel hair brush on larvæ of the Corn Borer in a suitable condition, or injected into the body cavity of the chrysalids of this species. The results of these experiments were very encouraging, and the procedure has now been utilised on a large scale by some of the entomologists working on the Dipterous parasites of the Japanese Beetle. It is obvious that these methods are capable of extension in various ways, and that we are, as yet, only in the initial stages of work of this kind.

To sum up the discussion of this phase of the problem, it may be said that by careful attention to details and consistent efforts to supply both parasites and hosts with an environment which approaches as closely as possible to the optimum, the process of breeding parasites can often be carried on in the laboratory or the insectary on an extremely large scale. The initial stages of work of this kind require, in every case, a careful investigation by trained entomologists, but when the details of the process have been worked out it can often be passed to relatively untrained assistants. There is no reason why the work of producing parasites in quantity cannot be carried out on as large a scale as any other industrial process, such as the production of machinery of various kinds. The initial expenditure is considerable, but once the work is under way it can be continued at relatively little cost, and may, in many cases, give results far superior to those which can be obtained by any other method. The work of Professor H. S. Smith in breeding Cryptolaemus in order to combat the Citrophilus Mealy Bug in California, to which we have already referred in the introduction, is an excellent example of what can be done in this way. In some cases, work of this kind can probably be carried out with fair success by the individual agriculturist, but usually it is more satisfactory to establish a centre in which the requisite facilities will always be available, supported by bodies of fruit-growers, farmers and co-operative organisations. That stations of this kind may be commercially profitable the experience of the Hawaiian Sugar Planters' Association has amply proved.

When the requisite supply of parasites or predators cannot be obtained by breeding the species in the laboratory—and, as we have already pointed out, this is often a task for which the entomologists in many parts of the Empire have, at present, neither the resources nor the equipment—it is necessary to rely on the collection of the material in large quantities in the field. The problem of collecting a

sufficient quantity of material in condition suitable for transport, of preparing it so as to reduce the likelihood of loss in a journey which may occupy a considerable period, and of moving it to its destination as rapidly as possible and under the most hygienic conditions is extremely important.

The collection of a large quantity of material is always desirable and often essential to success. The mortality due to careless handling during collection, to unsuitable methods of packing, unfavourable conditions during shipment, and accidents during rearing and liberation, is often considerable. In reading the history of attempts to introduce beneficial insects, one repeatedly meets with cases where collections of parasites or predators, obtained at great expense from far distant points, were completely lost before they could be utilised owing to the high death rate on the one hand, and the ridiculously small number of individuals collected on the other. The collection of large amounts of material adds, as a rule, relatively little to the cost of such undertakings and enormously increases the chances of success. Every effort should, therefore, be made to secure a large number of individuals of the species it is desired to introduce. In some cases, if collectors are to be maintained in the region considered, the collections need not be excessively large, but if they are merely visiting the district and have come from a considerable distance, they ought certainly to secure enough specimens so that a colony of several thousand individuals will be available for liberation at each point at which it has been decided to introduce the parasite or predator. As has already been pointed out, a liberation of a thousand individuals means the collection of a very much greater number owing to the unavoidable mortality which always occurs during the process of collection, rearing, and shipment.

The methods to be followed in locating an area where large collections can be made have already been described. When such an area has been found, the task of the collector is to obtain the amount of material desired within the time available for the work. The general character of the organisation necessary for this depends chiefly upon the amount of time available for the collection. If the insects to be collected are rather uncommon and are present in a condition where they can be obtained only during a brief period, as is often the case with parasites which go through the whole of their development during the summer months, then it is necessary to employ a large staff of collectors and push forward the work with great energy. If the

developmental stages of the host containing parasites or the parasites themselves, can be secured during the period of hibernation, whether facultative, as during a cold or dry season, or obligatory, as in many insects which have phases of dormancy more or less independent of external influences, the organisation need consist only of a few collectors. A highly trained personnel is not necessary for work of this kind. Since the collectors have to deal only with a very few insects they soon acquire knowledge sufficient for the work, which is not intrinsically more difficult than the collection of agricultural products, such as fruit or vegetables, or than many phases of industrial work. The collectors employed for prolonged periods must, of course, be chosen with greater care than those employed for short periods, since they may have to work more or less independently, and may have to deal with several different types of material. The most suitable personnel for collecting work of this kind is usually found among the native agricultural population of the district in which the work is done. Workers of this kind have, as a rule, some acquaintance with the material to be collected and are accustomed to labour of a closely allied type. Country schoolboys can sometimes be employed successfully.

The method and amount of payment to workers employed for large field collections demands careful consideration, in order that the greatest possible returns may be obtained for the funds available, which are sometimes unavoidably small. As a general rule the rate of payment should not exceed that which is usual for the class of labour in the region where the work is done. Higher rates of pay may facilitate matters at the outset, but are likely to give rise to difficulties later, either with the employers of the region or because the labourers themselves are apt to conclude that unlimited funds are available and that any demand, however unreasonable, will be met. The fact that payment is made for the collection of material considered by the labourers themselves to be quite useless makes it all the more necessary to conduct the whole operation on strictly business lines. The only case in which payment in excess of the customary rate can be granted is when the work to be carried on is of a particularly difficult or disagreeable nature, as for example, the collection of caterpillars with poisonous hairs, of larvæ living in offal or excrement, and so forth.

Whether payment should be made on a time or on a piece-work basis must be carefully considered in every given case. Each of these systems has its advantages and disadvantages. If collectors are paid

by the day or by the hour, careful record should be kept of the amount of material turned in by each worker so that unsatisfactory employees can be eliminated. If the workers are paid by the piece, some experiments must be made to find out how much material can be obtained in a given period when a reasonable effort is made, and the rate of pay should then be fixed in such a way that any effort above the average is justly compensated. When the collectors have acquired some experience their daily wages may, on the basis chosen, rise considerably above the current wages for the region, but as they can then be considered as specialised workers, there is no objection to this. However, when this mode of payment is adopted the material collected must be carefully inspected, otherwise a great deal of damage may be done to the collections by careless handling, which results from the attempts to work more rapidly than is consistent with the skill of the labourer. When direct surveillance of the labourers is necessary it is best to follow the industrial custom and appoint a foreman in each locality where collections are made. The foreman is then responsible for the conduct of the work, and is paid at a higher rate than his subordinates. This procedure greatly facilitates matters, especially in foreign countries and leaves the entomologist in charge free to devote himself to technical problems. Furthermore, as anyone who has travelled in foreign countries realises, it is much more easy to carry on an intelligible conversation with one person, to whose vocabulary and accent one has become accustomed than to make oneself understood by a large number of individuals. Again, the foreman can be a very useful intermediary with the agriculturists of the district in whose properties the material must be collected, or the work carried on. The employment of such locally known intermediaries is on general grounds highly desirable. Since they are locally known they can penetrate into regions or into properties where a foreign entomologist would be regarded with suspicion.

Agriculturists are usually quite willing to allow collectors to visit their properties and examine their fields or orchards during the process of preliminary collection. On the other hand, when large scale collections are made, matters usually take on a somewhat different complexion. In the case of some insects the work of collection necessitates the removal of a considerable amount of plant material from the fields or orchards. Sometimes this material is removed after the crop has been harvested and has very little value, as, for example, stubble, dried maize stalks, decomposing fruit, and so forth.

In other cases, the work necessitates the collection of fruit or portions of the plant, which are actually utilised by the agriculturist, even though they are more or less damaged in condition. In any event, whether the material is utilised or not, the fact that it is desired in large quantities, and that an obviously considerable sum is being spent upon its collection and examination, somewhat enhances its value. The collector must, therefore, expect to have to pay for the material he wishes even though its value upon the agricultural market is very small.

In all such cases the field agent must exercise great care in negotiating with the agriculturist, otherwise he will not only very greatly increase the cost of the particular project in which he is dealing, but will also prejudice the cost of any future operations in the district. When the material collected has obviously a marketable value, as in the case of fruits, which, although they are infested by insects, can, nevertheless, command a fair price, or of green crops used as forage, of which a certain proportion contains the egg or young stages of certain insects, the price offered must be usually more than that which the product commands in the open market. When the material utilised is in itself of relatively little value, the fixing of a price is a good deal more difficult. It is, however, desirable to fix a price which allows the farmer disposing of the material, reasonable and rather attractive profit, especially if it is desired to continue the work during several years, because the knowledge that stuff hitherto regarded as worthless, can be sold, will spread rapidly in the countryside, and the collector will find that eventually he is able to obtain delivery of large amounts of material, without any effort on his part, and without having to spend time in travelling over large areas of the district.

The actual process of collection and the treatment of the material immediately after collection need very careful study in every given case. It is usually possible, having regard to the situation of the organism to be collected, to divide the work into several different phases, which can then be taken up separately, with better results than if the collection is carried on in a haphazard manner. Thus, in working on the parasites of the insects attacking certain forage crops, the most satisfactory method is first to cut and harvest the entire field and then to turn over the material to a band of workers under the direction of a foreman, who examine it piece by piece and

separate the infested plants. These are then handed over to a second and more highly trained band of workers, who remove the eggs or larvæ of parasites and pack them for shipment.

In the case of leaf-feeding insects, sweeping with a net or beating with a sheet or umbrella are often very rapid and efficient methods of collection. In some cases mechanical apparatus will probably prove very useful. Thus, according to Johnson, one of his correspondents obtained from the apparatus used in shelling peas in the Southern United States, about twenty-five bushels of Syrphid larvæ, chiefly *Allograpta obliqua*; Metcalf (1916) estimates that this collection could scarcely represent less than 3,000,000 individuals. As this large quantity was obtained during the course of a few days' work the value of the method is obvious.

The separation of parasitised and unparasitised material can sometimes be effected mechanically. For example, the workers at the Gipsy Moth Parasite Laboratory of the United States Department of Agriculture, have devised a special machine for the separation of the parasitised and unparasitised eggs of the Gipsy Moth. The eggs of this moth are covered, during oviposition, by the female moth, with a thick pad of hairs, and after a collection has been made, the first operation consists in the removal of these hairs. According to Crossman, this was originally done by rubbing the egg-clusters with the bare hands or with a pad over a piece of cotton cloth, drawn tightly over a tray, until the hairs had been rubbed off; but for this method a mechanical plan has now been submitted. The machine used in this work consists of two discs about two feet in diameter, the lower one of which is stationary, while the upper one above it revolves, the power being furnished by a small motor. The inner surface of each disc is padded with felt covered with canvas. The upper disc works on a spindle and can be adjusted so as not to injure the eggs. The egg-clusters are broken up and fed into the machine through a box-like opening in the upper disc. As the disc revolves the eggs are gently rubbed between the two inner surfaces. As the eggs are worked to the circumference of the disc they become separated, cleaned and drop off, assembling in a jar below. The hairs that are rubbed from the egg-clusters are removed by means of a blower attached to the centre of the apparatus, and thus no ill effects result to the workers engaged in the process. After the eggs have been cleaned they are separated

into parasitised and unparasitised eggs. Formerly, the eggs were placed in trays, in the top of which were numerous one-inch holes. In each tray on top of the layer of eggs were placed one or two thicknesses of close mosquito netting, through which the small caterpillars had to crawl on leaving the tray. When the eggs and netting were in place, each tray was entirely covered with black paper and placed on a rack in a large room to allow the non-parasitised eggs to hatch. Before it was time for the non-parasitised eggs to hatch, the paper was broken over the hole in the front of each tray and glass vials were inserted, into which the caterpillars crawled. When hatching began, the entire attention of several men for nearly two weeks was required to remove the larvæ from the glass tubes. This was accomplished by clearing out each tube with a camel's hair brush, and placing the caterpillars in paraffin. After the process of hatching was complete the eggs were removed, and placed in a machine, so constructed that as the parasitised eggs, dead eggs, and egg-shells ran down a chute, the dead eggs and egg shells were drawn off by suction ; the parasitised eggs, which are heavier than the other material, assembled in a glass tube at the bottom of the apparatus. This method of allowing the non-parasitised eggs to hatch, so that the parasitised eggs could be separated from the rest of the material was a long and tedious process, and has now been discontinued. A little apparatus called a " bouncing machine " is now used for this work. The eggs are allowed to run down a wooden chute, at the bottom of which is a small piece of tin placed at right angles to the inclined surface. This piece of tin is termed the " take-off." When the eggs hit it, they bounce into the compartments of a box beneath. The eggs containing the parasite maggots do not have the same capacity for bouncing as the healthy Gipsy Moth eggs, and therefore fall into the first and second compartments, while the other eggs bounce farther and drop into the compartments beyond. The non-parasitised eggs are then destroyed. The eggs containing parasites are then put into small manilla envelopes in lots of about one thousand parasites each, for colonisation in the spring. These parasitised eggs are not actually counted but are measured in a small glass tube, so graduated that each colony will contain about one thousand eggs. The application of the method is, of course, strictly limited, but it has been described in detail since it is a very interesting example of the way in which work of this kind can be standardised so as to be carried on with a minimum of effort along the lines used in other industrial processes.

After the material has been collected it must be packed in a condition suitable for transport. The method employed will depend, of course, mainly upon the stage in which the material is collected and its physiological condition at the time of collection. In the case of parasite cocoons or puparia, eggs with hard shells, chrysalids, or hibernating larvæ, the method used is, in general, relatively simple, and the main points to be kept in mind are the provision of an environment neither too humid nor too dry. It must be remembered that organisms, such as hibernating caterpillars, or even parasitic cocoons, if packed together in large numbers in closed containers and left there during a considerable period will sometimes give off a considerable amount of moisture, which in turn will cause either overheating or the development of mould, and consequently a very high mortality during the process of shipment.

High mortality from the absence of moisture arises rather less frequently, possibly owing to the fact that under ordinary conditions prevailing in the shipping boxes, very little loss of the moisture content ordinarily occurs. Whenever excessive evaporation is likely to occur measures should, of course, be taken to provide humidity. A very successful method devised by Dr. J. G. Myers in the shipment of the larvæ of Sirex, consisted in putting the larvæ of this parasite in large gelatin capsules filled with sawdust. In other cases the material may be packed between layers of clean living sphagnum moss, which provides a supply of moisture without any danger of the development of mould.

The possibility of the interaction between individuals of the species shipped must be considered. Cocoons or puparia collected in the field are not infrequently infested by secondary parasites, such as *Dibrachys*, and unless the shipment is kept during the whole course of the voyage at a low temperature, individuals of these secondary species may emerge and attack the healthy parasites, so that when the material reaches its destination all the primary parasites have been destroyed. In order to avoid accidents of this kind it is best, whenever possible, to isolate the cocoons or puparia in individual tubes or gelatin capsules. The capsules are usually quite satisfactory unless the surroundings are exceptionally humid, when glass tubes must be used.

If the material collected is in a condition of obligatory dormancy, then it can be shipped during the winter months and no special arrangements need be made for preventing its development, though

on general grounds it is preferable to send it under such conditions that high temperatures are avoided. In many species, exposure to high temperatures in the condition of obligatory dormancy does not perceptibly accelerate development, but it may cause a rather serious mortality. If parasites or hosts are shipped in a condition in which the development is accelerated by high temperatures, arrangements must be made for shipment in cold storage. A temperature of from 40° to 45° Fah., is very suitable for shipments of this kind, and this temperature can practically always be obtained in the vegetable chill room of most sea-going vessels. In some cases it happens that material has to be collected during the summer months, and stored for some considerable time before it can be shipped, and must then be carried to the port of entry from a point so far distant that the journey takes from 24 to 48 hours. In this case, arrangements must be made for storing the material at the place of collection in small household ice-chests, and it must be carried to the port at which it is shipped in a portable refrigerator. A very convenient refrigerator of this type was developed by the entomologists of the United States Department of Agriculture, and consists of a steel valise, lined with a layer of thick felt, and containing three zinc boxes, of which the two end ones are about half the width of the middle one, and are packed with ice, while the middle compartment contains the specimens to be shipped. It is found in practice that once this box has been chilled down, it can be carried for a considerable time without a very great rise in temperature. A somewhat similar box for the same purpose is constructed by Chas. Hearson & Co., Ltd., of London. In making shipments of material, the development of which is notably accelerated by high temperatures, it is necessary to provide cold storage facilities, not only during collection and shipment, but on reception.

An important point concerning the shipment of insects whose development must be retarded artificially by refrigerators is that the effect of low temperatures on the various phases of development may be very different. Cocoons or puparia which have almost completed the process of development are extremely difficult to carry through cold storage. The adults sometimes emerge, in spite of the low temperatures to which they are subjected, and die before the material reaches its destination. Sometimes it is necessary to ship adult parasites, though few attempts to develop methods suitable for this purpose have as yet been made. The requisites appear to be a

combination of some satisfactory feeding method with moderately low temperatures, so that the parasites will remain active enough to feed, without exhausting themselves en route. Some very successful shipments of the adults of *Blastothrix sericea*, the parasite of *Lecanium coryli*, have been made from Farnham Royal Laboratory by placing the adults of this parasite, which is a very minute Chalcid, in glass tubes, simply provided with raisins attached to the inside of the cork. Several lots containing fairly large numbers of individuals were sent to the Dominion Parasite Laboratory at Chatham, Ontario, and trans-shipped from there to Vancouver, with a mortality averaging rather less than 10 per cent. The shipment of adult parasites is, in general, most likely to be successful with robust and hardy species. The Canadian Parasite Laboratory has however used it successfully with *Digonochaeta setipennis*, the Tachinid parasite of the Earwig, a relatively fragile insect, but which Mr. A. B. Baird of the Canadian Laboratory sent successfully from the region of the Great Lakes to the West Coast.

Whatever the material shipped, and whatever the method of shipment, all cases or boxes utilised should be solidly constructed and capable of being hermetically sealed, so that there is no chance that any undesirable insect will escape en route, or that any of the parasites shipped can find their way out of the boxes before the material reaches its destination. When glass containers of any kind are employed, plenty of packing should be used and the dimensions of the packing boxes should be sufficient to allow ample provision for this.

All shipments should be preceded or accompanied by a letter stating the names and numbers of the parasites shipped, the time and conditions of shipment and any information which is of interest concerning the methods of handling the material. If possible there should be included with the shipment, a set of pinned and identified specimens of the species sent. In this way the entomologist at the receiving end can proceed at once to separate and identify the material, and liberate the desired species of parasites or predators immediately.

7. *Methods of Treatment on Reception.*

The first step that the entomologist at the receiving end must take when he is advised of the arrival of a lot of parasitic material is to ensure its rapid conveyance, under the most favourable conditions, to the laboratory where it is to be dealt with. Very frequently, after the material is taken from the vessel it has to be sent to its

destination by rail. In such cases, if the distance from the port of entry to the ultimate destination is very great, the best method is to have the shipment conveyed by a special messenger, in cold storage, to the laboratory where the parasites are to be reared. In some parts of the world refrigerator cars exist on certain railway lines, but if these are not available the portable refrigerators must be used. In order that there may be no delay after the arrival of the material in the port of entry, the usual method is to advise the entomologist at the receiving end of the shipment by cable. It is then his duty to make arrangements with the authorities at the port of entry, or the shipping companies, so that he may be notified without delay, of the arrival of any packages of material. If the material has been transported in cold storage it should not be allowed to warm up too rapidly, as sudden changes in temperature may often cause mortality.

On the other hand, the treatment of the material after it has reached the laboratory at the receiving end, demands special attention. The points of greatest importance in this connection are that the consignments be dealt with as rapidly as possible, and that the packages be opened under such conditions that there is no likelihood of the escape of undesirable hyperparasites or other noxious insects. If through any unforeseen circumstance it is impossible for the staff of the laboratory to deal with the consignment immediately upon its arrival it should be placed in cold storage at once, but this must be avoided whenever possible. In order to prevent the escape of any undesirable insects, the packages containing the parasites should be opened only in rooms of which the windows are covered with fine wire gauze, or in insectaries specially built for the purpose and designed in such a way that the escape of any insects is impossible. Any adult parasites or predators which are found on opening the package, should at once be set aside and provided with food, and the remaining material separated into species and put aside for rearing.

In some of the large scale rearing experiments conducted in the past, as for example in the work on the parasites of the Gipsy Moth and the Brown Tail Moth, the material received was collected in various parts of the world by entomologists who had not previously carried out any investigations in regard to the habits of the parasites and predators sent. Consequently, before these could be utilised it was necessary, in many cases, to carry out extensive studies of their biology. It is now recognised that it is

much better and much safer to carry on studies of this type within the native home of the beneficial insects where information concerning their habits can be secured much more easily than in the country into which they are to be introduced. However, even though relatively full information in regard to the biology and habits of the various species has been obtained it is still necessary for the entomologist at the receiving end to take certain precautions, especially when the material received consists of parasite puparia and cocoons, which have been collected in the field and may have been attacked by secondary parasites. Furthermore, we know that there are certain parasites, which although they are secondary, actually attack the primary parasite while it is still within the body of the living host. Such for example are the Chalcids of the genus Perilampus, whose remarkable life-history was described a number of years ago by H. S. Smith. The possibility that parasites of this type may be present has some bearing on the methods of liberation and ought therefore to be mentioned.

The liberation of the parasites received may be accomplished in three ways. In the first place, the entomologist at the receiving end may liberate in the field the developing larvæ or caterpillars of the pest, of which a certain proportion is known to contain the younger stages of the parasite which it is desired to import. A sufficiently accurate idea of the number and specific identity of the species present can be obtained by dissection, and since the host insects are placed, as soon as they are received, in their natural environment, it has sometimes been considered that this method of liberation is, in the long run, the most satisfactory. However, as has already been stated in a previous section, it is very questionable as to whether the conditions which the average group of individuals of the species actually encounter in nature are really as suitable as those that can be provided in the laboratory. Unfavourable meteorological influences of various kinds and the activities of various predators, such as birds, beetles, etc., may very greatly reduce the population of larvæ or caterpillars liberated before the parasites have had time to complete their development. In view of this fact, it is usually preferable to keep parasitised caterpillars or larvæ in the laboratory, in an insectary, until the parasites they contain have emerged as adults. The rearing methods suitable will differ in the case of the different species studied, and need not be described in detail. They ought to be of such a nature

that individuals of the host which have pupated, or parasites which have emerged and have formed their puparia or spun their cocoons, can be removed from the breeding cages from day to day. One of the most useful pieces of apparatus yet devised for this purpose is the Fiske Tray, of which a photograph is given on Plate VII. This is simply a wooden framework, the bottom of which is closed by a sheet of cloth and in which a band of tanglefoot prevents the escape of the caterpillars. These trays have been used with success for the rearing of larvæ in very large numbers. They must be given attention during the rearing work as the caterpillars can very easily escape from them if a leaf or twig, introduced for food, happens to bridge the interval between the top of the tray and the inside. They require to be cleaned at fairly frequent intervals since the food, which is supplied in the form of freshly cut leaves or twigs is exposed freely to the air and dries up fairly rapidly. Their great advantage is, however, that all the material contained in the tray is easily accessible, and that parasite cocoons, larvæ, chrysalids, or puparia can be detected and removed with great ease. For larvæ which are too delicate to be transferred to fresh food at frequent intervals, and which will not move to the fresh food as the old food dries up, this kind of rearing tray is not suitable and cylindrical or cubical cages, which are large enough to contain growing plants or twigs in water, must be provided.

The moment when the parasite larva emerges from its host is, in the case of some species, very critical. Certain Tachinids, like *Sturmia scutellata* and *Pelatachina tibialis*, if allowed to emerge and pupate in trays or cages, generally die off in rather large numbers, particularly if they are left exposed to the air for any length of time. When such parasites are present, arrangements must be made so that when they emerge from their host they can descend directly into the earth. Many Hymenopterous parasites, if allowed to emerge from the body of the host on a perfectly flat surface or in a glass container, whose volume is much greater than that of their own bodies, are unable to form their cocoons and frequently perish after vain attempts to do so. The larvæ must, therefore, be removed immediately after their emergence and placed where they can obtain the right conditions for spinning.

Many parasites, after they have formed their puparia or spun their cocoons, remain in a condition of obligatory dormancy for many months, as, for example, during the winter season. With species of

this type it is often necessary to regulate the humidity condition with some care, and the specimens must sometimes be buried in earth under outdoor conditions, if satisfactory emergences are to be obtained.

Finally, there are some species which pass the winter in a condition of obligatory dormancy, but which are, nevertheless, not completely indifferent to fluctuations in temperature; which are, in other words, in a condition of imperfect diapause. If such insects are kept in a warm room throughout the winter they will develop and emerge many months before the host is available in a stage suitable for attack. Care must, therefore, be taken to retard their development until such time as the host is available, either by placing them out-of-doors or by leaving them in a refrigerator during the winter months.

The rearing of parasites sent from Europe to the Southern Hemisphere or from the Southern to the Northern Hemisphere presents special problems. If the parasites are of the type which emerge in the same season as that in which their development began, it is usually rather difficult to retard them sufficiently to bring them from the point where they are collected to countries like Australia, South Africa or New Zealand, and even if they arrive alive it may still be extremely difficult to induce them to survive until the host is available in the field. On the other hand, if the parasites are of the type which spend the succeeding winter in a condition of hibernation and emerge normally in the following spring, attempts to force them to develop in time to attack the early stages of the host in the country in which they have been introduced may not be successful, or, if emergence is obtained it may occur at a time when there are no longer any hosts available in the field. In such cases it is, therefore, necessary to leave the parasite or predator in cold storage till some three or four months after the moment of normal emergence, and this long exposure to abnormal conditions has, not infrequently, prejudicial results. Whenever it is possible to do so the correct method of procedure with such species is for the entomologist at the receiving end to rear the hosts continuously, so that individuals in all phases will be available at the time the shipment of parasites arrives. In this way he can obtain another generation which can be placed in cold storage until the hosts appears normally in the field.

The next step after the rearing of the parasites and predators in satisfactory numbers from the material received, will either be the building up of colonies large enough for liberation by breeding work

in the laboratory, or the liberation of the imported material directly in the field. The methods of breeding have been dealt with in a preceding section, and we need not return to them here. The question of colonising, however, merits a little further attention. The main points to be considered are the number of individuals to be liberated, the condition in which they should be when liberated, the time at which they should be liberated, and the choice of localities in which to colonise them. It is very difficult to make any satisfactory statements as to the number of individuals it is desirable to liberate. The main advantage of the method of biological control is generally held to be that it is self supporting, and if this view is taken, of course, all that is desired is the establishment of the species in the new home. However, in order that this may be brought about with certainty, and in order to avoid the disastrous results of climatic irregularities affecting any particular point in the new home, it is desirable to make the introduction in a number of different localities, which differ in agricultural, topographical, or climatic characters. In each of these localities a colony of as many individuals as possible ought to be liberated in a single spot. This spot should be one containing a population of the host as dense as possible, and in which no heavy mortality due to artificial or mechanical controlling factors is likely to occur for a fairly long time to come. If populated regions are used for the purpose of colonisation it is as well to make special arrangements in order that methods of mechanical control may be abandoned until such time as the establishment and dispersion of the parasites is demonstrated.

Whether it is proper to employ mechanical measures of control after the establishment of the introduced parasites or predators has been the subject of debate. Trouvelot considers that the effect of these measures is generally more prejudicial to the parasites than to their hosts, either because they cause such a diminution in the population of the pest that the parasite cannot find enough hosts for its progeny, or because they destroy a larger proportion of parasites than of hosts. Volterra in his important work on the variations and the fluctuations in the number of individuals in species of animals living together, maintains on mathematical grounds, that if we remove from their common environment the same proportion of two species, the first of which feeds upon a medium considered as omnipresent and inexhaustable, while the second feeds upon the first, the population of the predacious species will fall more rapidly than that of its prey,

owing to the increased difficulty it experiences in finding food. The results of these calculations are said to agree with the statistical studies made by d'Ancona of the Adriatic fisheries, where it was found that the interruption of fishing due to the war was followed by an increase in the proportion of the predacious forms. The present writer has, on the contrary, argued, also on mathematical grounds, that unless mechanical methods destroy a larger proportion of parasites than hosts, their effect will not be injurious. In expressing this view, he had, however, in mind cases in which the host population was still increasing, in which hypothesis mechanical control would not adversely affect the food supply of the parasite, unless it were so effective as to transform the increase of the host population into a decrease. In the case of pests of which the populations have become stable, it is quite conceivable that mechanical measures of control may considerably reduce the effective reproductive rate of the parasite, not only by destroying its progeny, but also by preventing it from producing its full quota of young owing to the rarefaction of the host population which it determines. The subject is, however, more complex than it appears on first sight, and requires further study, not merely from the theoretical but, more particularly, from the experimental standpoint. In any event, few entomologists will advise agriculturists to abandon mechanical control in order to favour the increase of parasites or predators, simply because mechanical methods produce in most cases a certain immediate benefit, while the benefits to be derived from favouring the increase of the parasite are, in most cases, somewhat problematical.

The moment at which parasitic and predacious species are to be liberated has given rise, in the past, to some controversy. Some entomologists, believing that the best method is essentially to place the parasitic or predacious species in its natural environment as soon as possible, and that in this environment its chance of survival is much greater than in the laboratory, have maintained that individuals ought to be liberated in the field as soon as they emerge and are completely formed. Others, on the contrary maintain that owing to the small size of the population the process of dispersion is likely to separate the males and females before they are ready to mate, so that the latter will perish without producing any progeny, or produce progeny which are only of the male sex. There are certain number of species, particularly in the group of the Diptera, in which there is an interval of many days or even

several weeks between fertilisation and oviposition. It has been claimed that with these parasites the best results will be obtained by keeping the females in captivity until they are ready to oviposit. The difficulties which have been encountered in the attempt to establish certain parasites seem to suggest that in some cases, at least, it is better to ensure the mating of the sexes before the liberation of the species, but we have, at present, no accurate information concerning the comparative rates of mortality of the adults in the laboratory and in the field. The provision of a perfectly suitable laboratory environment for active winged insects is, however, a problem more difficult than that of dealing satisfactorily with larval stages. The attempts made up to the present by the writer to rear Dipterous parasites in captivity have never given very satisfactory results, since by the time the individuals reared are ready to oviposit they are usually in an extremely damaged condition and far inferior to the specimens of the same age that one habitually collects in the field. They would obviously be unable to survive for any length of time if they were liberated. The utility of this method is, therefore, somewhat questionable.

During the work on the parasites of the Gipsy Moth carried on in 1908, C. H. T. Townsend attempted to solve the question of colonisation by inducing the Dipterous parasites which he was studying, to oviposit in captivity on young larvæ of their host which were then liberated directly in the field. The results of these liberations do not seem to have been very satisfactory, and so far as the writer is aware, no further attempts of this kind have been made.

The question of the moment when parasites should be liberated is relatively simple. Colonies of individuals ready to oviposit should be turned loose at a time when the host is available in the field in a state known to be attacked in the native home ; or, if the parasite is liberated before the host is in this stage, it should itself be in a correspondingly earlier stage of development. Information concerning the stage in which the host is habitually attacked should, therefore, be obtained in the native home of the insect and supplied with the colony to the entomologist at the receiving end.

8. *The Study of the Progress of Introduced Parasites in the Field.*

As has already been said in a previous section, the chief advantage of the method of biological control is generally held to be that it is self supporting, and this view is perfectly justified in so far as the

individual agriculturist is concerned. It is, however, very desirable and sometimes necessary that the progress of an introduced species be followed by a technical expert, at least for a number of years after colonisation, in order to ensure, in the first place, that the species introduced has actually become established and, in the second place, that we may determine with accuracy exactly what effect it has in controlling the pest which is being studied. This work should be done as accurately as is possible with a view to obtaining precise quantitative data in regard to the increase of the parasite and its effect upon the host. Unless an attempt to provide data of this kind is made by the entomologists importing parasites it is very difficult for the students of biological control to arrive at any satisfactory conclusions regarding work that has been done. It has happened not infrequently in the past, that introduced parasites have been given the credit for the temporary rarity or disappearance of the host although this rarity or disappearance may have been due to factors of an altogether different order. It is therefore necessary to point out that it is quite insufficient for scientific purposes to state that after the introduction of a parasite a reduction in economic damage has occurred. It is absolutely necessary to demonstrate by a careful series of rearings and dissections that the reduction in damage is due to the parasite and that there is no reason to suspect that the changes produced have been caused by variations in any other factors.

During the first few years after the distribution of a parasitic or predacious species it is, of course, sometimes impossible to find the species in any numbers and attempts to demonstrate its presence by dissection require so much labour that they are often quite impracticable. In this stage of the work it is therefore quite sufficient to make large collections which are reared with care, preserving for identification any parasite which is obtained from them. An attempt should, however, be made to plan the observations in advance in some consistent and rational way. A number of points within the infested area should be selected and in each of these a large number of larvæ should be collected year after year, in such a way that it will be possible to obtain a fairly accurate idea as to the increase of the percentage of parasitism from generation to generation. The oviposition period of the parasite may extend over a period of several days or weeks. Collections of the host in a stage suitable for attack should therefore be made during the whole period in which these

are present in the field and the average percentage of parasitism should be calculated from these collections made over the whole of the region considered. An effort should also be made to collect as much data as possible in regard to the interaction of the introduced species with other parasites attacking the host in question and with other host insects normally present in the area. Each introduction of a beneficial parasite or predator is an experiment carried on in an extremely large scale in nature and unless the results of these experiments are carefully kept the progress of the study of biological control will necessarily be extremely slow.

9. *The Results of Experiments in Biological Control.*

In the preceding sections the practical methods employed in work on biological control have been discussed. We have now to consider the important question of the results which may be expected from experiments of this kind.

Although work on biological control has been going on for a relatively long period, our knowledge in regard to the subject has not advanced very rapidly. One reason for this is that the progress of the introduced parasites and predators and the results which have followed their establishment have not been studied with sufficient care. Another is that the practice of biological control presents peculiar difficulties, as compared, for example, to such methods as spraying, which can be conducted on orthodox experimental lines.

In the most common form of experiments in the field of biological control we introduce the beneficial insects attacking a noxious animal or plant into an environment in which they have never before been observed. It is, however, obvious, that the effectiveness of the introduced parasites or predators will depend not simply on the presence and abundance of the host insect, but on a precise and definite combination of the environmental factors. If we introduce a beneficial insect into two different regions inhabited by the same pest the results may be very different, as experiments have repeatedly shown. The introduction of a beneficial insect into a new country thus constitutes, in a certain sense, a new and unrepeatable experiment. For this reason it is very hard to draw any conclusions of absolutely general value from the work that has been done, especially since it is often a very long time before any experiment can be considered as concluded.

We are therefore obliged to supplement the results of our observations in practical cases by theoretical considerations, which are, of course, in large measure, of the mathematical order, since the problem is mainly one of numbers.* The procedure here is to begin with the more general facts of parasite and host interaction as it occurs in nature. These facts are then stated in mathematical language and can then, by mathematical artifices of various kinds, be examined from various aspects, so that all the deductions concerning the numerical relations involved in the hypothesis can be obtained, with much greater ease than by ordinary reasoning. There are two serious pitfalls in work of this type. The first is the attempt to extract more from the end of the mathematical operation than was put into it at the beginning, or, in other words, the attempt to apply conclusions valid only in certain special cases, to phenomena of a much more complex order and which differ radically in some way from the case taken as a basis for the work. The second is derived from the fact that the mathematical methods most useful in work of this type have been evolved by the physicists in work on problems of mechanics and consists on the reliance upon dangerous analogies with inorganic systems, in the framing of the basis hypothesis. The difficulty of avoiding these pitfalls is considerable, so that, not infrequently, we are obliged to retrace our steps and recast our fundamental assumptions. In spite of this, however, the combined efforts of the students on biological control have gradually clarified our ideas, so that the broad general outlines of the theory of the interaction of beneficial insects and their hosts are now fairly apparent.

As has been said in the first section of this part, the basic theory of operations on biological control rests on a few very obvious facts. The potential reproductive rate of organisms is such that if all the offspring of every individual of any species survived in every generation they would, in a relatively short time, occupy the entire

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* Several mathematicians and biologists have contributed to this subject; but the most important work by far is that of the eminent Italian mathematician, Vito Volterra, published in 1926. By utilising the methods of the Calculus, Professor Volterra has succeeded in elaborating an absolutely general theory of biological associations; the fundamental importance of which is not yet generally realised by biologists, owing to the highly mathematical form in which it is presented. The deductions made by this author have been of great help in dealing with the matters discussed in this section.

area of the globe. Nevertheless, organisms do not increase uninterruptedly. On the contrary, their populations often remain relatively stable, or present oscillatory movements of which the periods and amplitudes vary with different species and under different conditions. In other words, we may say, in a general way, that the *normal* condition is *control*, while *outbreaks* are *abnormal*.

The fundamental explanation of this fact is, of course, that every organism has certain specific characteristics, which though they actually oscillate about a mean, may be considered for practical purposes as fixed. These specific characteristics imply and indeed include specific needs and specific powers, limited in certain particular ways. For example, in order to subsist, every organism requires a certain set of physical conditions, a certain type of food, and a place where the other organisms which prey upon it cannot attain it. Given an absolutely optimum environment, indefinite increase at a specific rate is possible. But the environmental conditions of the globe vary from point to point and are probably in no two places exactly alike.* From this it follows, that at a given moment in a given area, the precise environmental complex constituting the optimum for a given species will be found at relatively few points. When conditions in a locality inhabited by a given organism approach the optimum, the species automatically increases in numbers. This increase constitutes what we call technically an outbreak, but it is, of necessity, as we have already said, an abnormal phenomenon. The organism considered may increase in numbers for a considerable time but it obviously cannot go on increasing indefinitely. As it increases in numbers it necessarily spreads, both in space and time and during its spread it moves to points outside its optimum environment, when its rate of multiplication immediately diminishes. A progressively increasing number of individuals die without producing offspring. A progressively increasing number of the offspring which are produced, fail to survive. In other words, the effective rate of reproduction progressively diminishes, and the population ceases to increase ; control has been re-established.

* The discontinuity and variability in habitats, produced by the physical factors, both in time and space, is undoubtedly the primary extrinsic factor of natural control. At every moment in its life history an organism requires a certain specific habitat. As these habitats are scattered about over the environment the organism is obliged at certain intervals to traverse zones which are more or less unsuited to it, and it is during these intervals that the highest mortality usually occurs. Competition for food does not seem to be of great importance, except in certain special cases.

If we examine the situation at a time when the population of the organism is stable, that is, when it is neither increasing or decreasing, we shall find that a large number of environmental factors combine to produce this result. In practice it is found that the qualitative and quantitative composition of the complex of environmental factors varies at different times and in different places. Nevertheless, as was long ago shown by Howard and Fiske, they can be broadly classified into several different groups, which act in different ways.

The first group of controlling factors comprises those agencies described by Howard and Fiske as the *catastrophic* factors, but which it would be better perhaps to describe as *independent* factors, since the effect which they produce is essentially independent of the number of individuals in the population upon which they are acting. This group is composed of the factors comprising the physical environment in the broad sense of the term. The mortality resulting from the action of meteorological causes, such as rainstorms, excessive heat or cold, excessive humidity or drought, and so on, is about the same, other things being equal, whether the population is large or small. Thus, in rearing insects under laboratory conditions, we find that whether the number handled is large or small, providing, of course, that sufficient assistance to deal with it adequately is available, approximately the same number of adults is secured. The proportion of eggs failing to hatch and the death-rate during a given stage and under given conditions, remains practically constant, whatever be the population handled. This does not mean, of course, that when the population in the field increases, the percentage of individuals destroyed by a given physical factor will necessarily remain constant. On the contrary, the proportion of individuals destroyed by this factor may quite possibly be considerably larger than before. But this would be due to the fact that in increasing and spreading, a larger proportion of the population has moved out of the optimum physical environment and consequently become accessible to the action of the physical factor. In such a case it would not be the numerical increase in itself which is the cause of the increased mortality, but the secondary effects produced by this increase. If the environmental conditions were homogeneous, the numerical increase of the population would not have brought a larger proportion of individuals into unsuitable physical conditions and the proportion destroyed by the independent factors would have remained the same.

The second group of controlling agencies comprises what may be called the *individualised* or *dependent* factors of control, so-called because the intensity of the effects which they exert is in some way directly dependent upon the number of individuals in the population of the organism on which they are acting. This group includes not only the various parasites, predators, and pathogenic organisms, which prey upon and develop at the expense of the species considered, but also the organism itself. The reasons why the intensity of the action of these factors is dependent upon the numerical value of the population on which they are acting is that they are *limited*, not only in space and time, but also in their destructive capacity. A parasite belonging to a given species can only deposit a certain limited number of eggs; a predator can only devour a certain limited number of its hosts. The larger the population of the organism upon which they are acting, the smaller the fraction of this population which each individual parasite or predator will destroy. On the other hand, the more numerous the host population the more completely the parasites and predators will be able to realise their potential powers of reproduction.

This group of factors can be further sub-divided in various ways. In the first place they can be classified according to the nature of the effect they exert upon the organism upon which they act. Thus the action of what we usually call natural enemies is *directly destructive;* they prey upon and destroy individuals of other species. Organisms inhabiting the same environment can, however, produce effects upon each other which are *indirectly destructive*. The reduction in numbers and in reproductive rate is brought about in this case by the occupation of habitats suitable for other individuals and by the alteration of the character of these habitats in such a way as to make them unsuitable for other species.

In the second place, we may classify these factors according to their degree of dependence upon the numbers of the organism they attack, that is, upon the way in which their intensity of their action varies with the variation in numbers of the organism on which they act. The rapidity of increase of parasitic and predacious insects with markedly specific host relations depends to a large extent on the density of the host population. There are, however, certain parasites and predators, whose rate of reproduction is relatively little affected by the variation in numbers of any one of the species they attack, either because they are able to utilise a large variety of organisms for food, or because relatively large increases

in the numbers of the species upon which they feed affect their rates of reproduction relatively little. Such are the vertebrate predators and many of the predacious insects, as well as the polyphagous parasites. Such are also the pathogenic organisms, which appear to increase only when certain exceptional physical conditions accompany the increase in the numbers of their host.

Without discussing any further the characteristics of all the factors enumerated, let us consider more particularly the effect of variations in the intensity of the independent, as compared to the most characteristic group of the dependent factors, that is, the specific parasites and predators whose multiplication and development depends in large measure upon the numerical variation in the populations of certain definite species of hosts.

Suppose we have a population of one hundred female individuals per unit of area living in a region where the physical conditions are such that of the six offspring each individual can produce only one pair survive in every generation. If the intensity of the physical factors suddenly decreases, so that all the six offspring survive in every generation, in four generations there will be 64,800 female individuals per unit of area. If then the physical factor returns to its former intensity so that as before, four out of six offspring are killed, the population will again become stable, but at a higher level than before. Similarly, if the population was depressed below the level of one hundred individuals per unit of area by an increase in the intensity of the physical factor, it would remain stabilised at the lower level in spite of the return to normal conditions.

The effect of variation in the intensity of the dependent factors, that is, the parasites and predators, is very different. If the host population has become stabilised at a definite value and a considerable fraction of the parasite population is accidentally killed off, the pest will begin to increase, unless some unfavourable condition intervenes ; but this increase in the abundance of the host will be favourable for the parasite, by making it easier for it to find hosts, for although the *potential* power of the parasite of locating its prey is dependent upon its specific habits, its *effective* power depends mainly on environmental conditions, among which one of the most important is probably the relative density of the host population. The parasite will thus increase more rapidly than before and if the host population had been stabilised before this increase began, it will progressively reduce its numbers until the effects produced by its own multiplication, such as superparasitism, rarefaction of the host population, etc.,

begin to effect it adversely. It will thus automatically reduce the host population to something near its original level. A similar effect will be produced if the numbers of the host are accidentally increased through the temporary decrease in the intensity of some physical factor, and stabilised at a higher level.

Now, other things being equal, the economic significance of a pest depends upon what we may call, roughly, the number of individuals per unit of area, that is, upon its population level. The fact that they are able to reduce the population level of their hosts is, of course, the principal reason for the importance attributed to the parasites and predators of destructive insects.

When a pest is transported into a new environment without the natural enemies which habitually attack it in its native home, it will begin to increase and spread, provided food material in the proper stage of development is available and the physical factors acting in the new environment are not more adverse to the pest than they were in its native home. It is, of course, evident that this increase and spread cannot continue indefinitely, for the reasons given at the beginning of this section, even in the absence of the natural enemies. The entire biogeographical area suitable for the species must eventually be occupied and after this point a very large proportion of the offspring will continually overflow, both in space and in time, into unsuitable environments. Finally, in extreme cases there may be a serious diminution of the food supply, which further reduces the number of adults able to reproduce and offspring able to survive. However, when the population has reached this point, its level will in all probability be very considerably higher than in its native home, and consequently the importance of the species as a pest will be immensely greater. Occasional fluctuations in the severity of the physical factors may, from time to time, reduce the population level, but in this case the effect would, in all probability be only temporary, because one of the most important reasons why the pest has ceased to increase is assumed to be that all of the available suitable environments have been occupied.* The partial destruction

* This does not necessarily mean that all the food has been devoured, or all the suitable habitats occupied, but simply that, at a given moment, all of the offspring of the *average* individual that are able, *on the average*, to get to places where food, suitable physical conditions, and freedom from the attack of enemies *all* co-exist, have, so to speak, taken up their positions. There is almost always an abundance of food, but the organisms cannot get at it.

of the population would liberate a number of these environments and permit the effective reproductive rate of the pest to rise, so that it would soon regain its original level. It therefore seems logical to introduce the controlling factors, whose intensity varies in proportion to the numbers of the pest, that is to say, the parasites or predators which attack it in its native home.

The success of this introduction as a measure of control will depend, of course, in the first instance, on the effect which the new environment exerts upon the introduced species. If the physical factors affecting it are less favourable than in its native home it will either not be able to increase, or will only do so extremely slowly, in which case, although it multiplies at the expense of the host and will theoretically reduce its numbers, it probably will not produce any susceptible economic effect within any reasonable time. It is thus extremely important for the entomologist of the area into which the parasite has been introduced, to follow its progress carefully from year to year so as to determine with certainty whether it is increasing or not. Although the introduced species is able to increase for a considerable number of years it may in some instances cease to do so before it has produced any measurable economic effect, partly because the temporal and spatial relations of the host to the new environment differ in some way from those which exist in the native home. Suppose, for example, that a pest, which, in its original environment, lived upon or near the surface of the plant it attacks, adopted in its new home, a habit of burrowing more deeply ; in that case a parasite which was able to attack a large proportion of this species in its native home would kill a smaller proportion in the new environment, and as has been shown elsewhere, the effect of this might be to arrest completely the progress of the parasite before it had produced any noticeable reduction in the numbers of the host, a proportion of the offspring perishing through super-parasitism and the remainder through the inability of the parent to find hosts.

Let us suppose, however, that conditions are relatively favourable to the parasite and it is able to increase in its new environment until its population becomes quantitatively equal to that of the host.

Even under these conditions the course of events may not present a very satisfactory appearance.

Perhaps the most important point to remember in this connection is that during the period which follows the introduction and establishment of a species, and the time when it has reached the highest population that it can attain in the area, there is an intermediate period during which the species increases slowly but steadily in numbers, but during which this increase may be masked by local irregularities of various kinds, so that in one locality the parasite may appear for a certain length of time to increase with extreme rapidity, while in another it exerts absolutely no effect, after which it may disappear from the first locality and become abundant in the second.

It is evident that, other things being equal, the phenomena which will follow the introduction of a parasite or predator depends, on the one hand, upon its rate of increase, and, on the other, upon the precise manner in which it spreads. Suppose, in the first place, that the rate of increase and the rate of spread are uniform, that is to say, that the species increases at the same rate over the whole area in which it is distributed, and that it also spreads at a uniform rate so that the population continues to be evenly distributed. In this case collections at any point in the area in which the parasite has become established will give very similar results. Nevertheless, even in this case the data obtained in regard to parasites belonging to different species may be very different. If the rate of spread is very slow in relation to the rate of increase the collections may indicate a perceptible rise in parasitism from year to year, but with a very localised distribution of the parasite. On the other hand, if the rate of dispersion is relatively rapid, as compared to the rate of increase, the collections made, even though they contain large numbers of the host, may completely fail to demonstrate the presence of the parasite, even for a considerable period. It is at present, hardly realised, even by entomologists, how enormous the population of an insect actually is and how tremendous is the disproportion between the populations of introduced beneficial insects and the population of the pest among which they are liberated. Even in moderate infestations several million individuals of the pest are often present in every acre of the infested territory. Supposing that the population of the pest is only one million per acre, then in a square mile of the crop attacked, there would be 640,000,000 individuals. If we liberate in such an area a colony of 1,000 female parasites, there will be only one parasite to 640,000 individuals of the pest. In such a case the rise in proportion of the parasitised hosts would necessarily be slow, unless the effective reproductive rate of the

parasite was very much greater than that of the host. Thus, suppose that the effective reproductive power of the parasite was twice as great as that of the host and that both host and parasite had only a single generation in a year. In that event, under conditions quite favourable for the progress of the parasite it would have to reproduce at the expense of the host for eighteen years before its population became equal to that of the host, *and in the fourteenth generation the percentage of parasitised hosts would actually be less than three per cent.* So far as can be determined from theoretical calculations, which are, as a matter of fact, in very fair agreement with the results obtained up to the present in practical work, the progress of events over the area considered as a whole, may usually be described by saying that the curve of the percentage of parasitism rises very slowly for a considerable time and then, when the end of the parasitic cycle is near, more and more rapidly until the work of extermination is complete, or the parasite has reached its numerical limit and ceased to increase. This means that during a number of years following the introduction of the parasite, its increase may be practically impossible to detect because of the local variations in numbers, even although its progress is, in fact, quite satisfactory. From this we may conclude that there is no reason to be discouraged, even though no perceptible results follow immediately on the introduction of a parasitic species or even for *many years afterwards.* In other words, experiments which are proceeding in a quite satisfactory manner and are, in fact, predestined to success, may present the appearance of failures. The method of biological control is not, in most cases, one which can be relied upon to give rapid results, at least in temperate climates. Its value, when it is successful, lies chiefly in the fact that it produces eventually, a permanent improvement in the agricultural situation with very little initial cost. Future generations will benefit from the results obtained, but they will also inherit the effect of any imprudent measures undertaken with a view of accelerating the process of control. Great care must, therefore, be taken to determine whether or not the results of an introduction are successful before taking any further steps.

The second case to be considered is one in which the rate of increase is uniform over the area considered as a whole, but the rate of dispersion is irregular, that is to say, in which the parasite remains confined to small areas scattered here and there throughout the district. In such a case the agriculturists in one locality may report results

that are almost incredibly satisfactory, while those from other areas report complete failures. Owing to the change in local climatic or other conditions, the conditions may be reversed in a few years time. The entomologist must, therefore, be as much on his guard against premature reports of success as against premature complaints of failures. Sometimes the localisation of the parasite in certain small areas may be a purely accidental phenomenon, so that after a few years the parasite spreads over the whole of the area. In other cases, however, its failure to spread may be due to the fact that its powers of locomotion are inadequate, and in this event it may be necessary to spread the parasite by artificial means, such as the United States Bureau of Entomology has found it necessary to use with *Anastatus bifasciatus*, one of the egg parasites of the Gipsy Moth.

In considering the effects of the introduction it must also be remembered, that at the time the beneficial species are liberated, the pest may not as yet have reached its limit in the new environment, but may still be on the increase, spreading year by year into new territories and producing greater and greater destruction in those it already inhabits. If the host population is increasing, the parasite will not overtake it unless its reproductive rate is equal to or greater than that of the pest, though, of course, it may do so after the host population has become stabilised. If the reproductive rate of the pest and its parasite are equal, the parasite will eventually overtake it, but the process will be very slow, the time required for control, other things being equal, being determined principally by the relation between the initial populations of the two species. If the reproductive rate of the parasite is greater than that of the host, the time required for control will be considerably lessened, a slight superiority in reproductive rate being a great advantage. Thus, a population of a thousand parasites, reproducing one and a half times as fast as the host, might under certain conditions overtake a population of a million individuals of the latter, in only fourteen generations. Under the conditions postulated, and supposing that all of the individuals of the host are accessible and attacked by the parasite introduced, the moment when the parasite overtakes the host will theoretically be marked by the total extermination of the latter followed by that of the parasite ; or, in a practical case, by a very considerable reduction of the host population, after which the parasite population will also be decimated owing to the rarity of the host, the condition thus produced forming a point of departure of a new cycle of development.

However, in spite of the fact the host is ultimately almost exterminated by the parasite and that the percentage of hosts destroyed increases from generation to generation no reduction whatever in damage will be produced until the generation in which extermination occurs. On the contrary the pest will steadily increase in numbers and consequently in destructiveness. Although its rate of increase from generation to generation will gradually diminish, the general situation, considered from an economic standpoint, will steadily become not better, but worse and worse until the climax is reached.

If the host population has reached its maximum and become stable, and the introduced parasite or predator is capable of increasing in its new home then immediate benefit may be expected, provided the increase of the host has not been checked because its population is too large for the area, in which case, as has already been said, the loss through parasitism might, at least for a time, be counterbalanced by the increase in reproduction, due to the fact that localities suitable for the offspring can be more easily found ; and provided also that the individuals destroyed will not naturally succumb, even in the absence of the parasite, through the action of other controlling factors, in which case the action of the parasite will have no effect until it becomes abundant enough to kill individuals which would otherwise survive. If the host is destroyed in the pre-destructive stage the dimunition in the damage produced will naturally be more rapid than when it is killed at the end of the destructive stage in its life history, but in any event, under favourable conditions, the action of the introduced parasite or predator population should produce an immediate, if slight, reduction in economic damage.

As has already been said, the rapidity of the increase of the parasite at the expense of its host and consequently the length of the interval between the time the introduction is made and the time when an appreciable reduction in economic damage occurs, appears to depend principally upon the effective reproductive rate of the parasite and is relatively little affected by the rise of the initial population. It follows from this that attempts to produce rapid results by liberating an enormous population of the parasite, or by making repeated introductions of the same species year after year are not likely to give results commensurate with the expenditure involved, though these introductions are, of course, justifiable if designed to establish and spread the beneficial species.

As we have already said there is, theoretically, at least, a possibility that owing to the inaccessibility of a fixed proportion of the hosts, the parasite population might be unable to overtake the host during the period of its increase, destroying in each generation a high percentage of hosts, but remaining economically ineffective. This is probably a partial explanation of the curious case of the parasites of the Alfalfa Weevil, which have increased in the Western United States until they destroy, in many districts, over ninety per cent. of the Weevil larvæ, the adults of the parasites being actually more abundant than the Weevils themselves, and are, as yet, unable to prevent economic damage.

Let us now consider more particularly the events which are likely to follow after the parasite has reached the limit of its increase ; that is to say, has reduced the numbers of the host to such a point that the rarefaction in its population has prevented the beneficial species from increasing further.

As we have already said, this rarefaction may be abrupt and catastrophic in cases where both parasites and hosts are increasing, while if the host population becomes stable before the parasite overtakes it, the diminution in numbers is likely to be gradual, unless the beneficial insect has exceptionally rapid powers of increase.

It is highly probable that the level to which the population of the pest is reduced when the parasite overtakes it during a period of increase is much lower than that to which it will fall if it has become stabilised during the progress of its enemy. The chance that any given parasite will find a host may be considered to depend more or less directly on the density of the host population, so that if the number of parasites finding hosts be represented by p_0, the number of hosts by h, the number of parasites present by p_1, and the dimensions of the total area by A, the relation between these values could be very roughly expressed by the simple equation :—

$$p_0 = \frac{p_1 h}{A}$$

The fall of the curve represented by this equation for equal decrements of h is at first rapid, but becomes slower and slower as the value of h diminishes. This means that the effect of the increase of the parasite at the expense of the host will be to cause a rapid decrease in the number of hosts it finds, so that its rate of multiplication soon

slows down and the population eventually becomes stabilised at the point where its destructive capacity is balanced by the loss in progeny, or oscillates about this level.

When the parasite overtakes the host at the end of a period of increase the effect will be exactly the opposite. The increase in the density of the host will facilitate the attack of the parasite, and, as has been shown elsewhere, the loss through superparasitism may not be sufficient to prevent its advance. The result will be the simultaneous disappearance of the vast majority of the individuals of the host, after which the parasites, unless they are species capable of attacking other hosts will disappear in their turn, so that the population will fall far below the level it would reach in the first case studied, and an enormous reduction in damage will immediately ensue. In the last generation of its abundance, the vast majority of the host larvæ will produce, not adults of the host but parasites. These will emerge in vast numbers in the following generations, but the number of individuals of the host per unit of area will now have fallen far below the point where the average individual of the parasite is able to reproduce so that unless it is a polyphagous species, able to utilise other and perhaps less favoured hosts in times of scarcity, it will be decimated in its turn. In the generation of its maximum abundance, the parasite will, however, succeed in destroying a certain proportion of the remaining hosts because of the thoroughness with which the area is explored. But the number of parasites which issue in the following year will necessarily be very small. There will then occur a series of what the physicists call "damped oscillations," i.e., fluctuations in the numbers of the two species which are at first considerable, but gradually decrease in amplitude, with a gradual movement of the populations to a higher level.

The reason for this is that the hosts and parasites are widely scattered and, on the average, widely separated, so that a large proportion of the former will escape their enemies, the population of which will fall still further. The increase of the host will thus go on for a considerable period; but as it becomes more numerous, the parasites, having increased facilities for reproduction, will also become more numerous and will eventually catch up with the pest. However, the population level at which this will occur will evidently be much lower than at the end of the first cycle, because the numbers of host and parasite are much more nearly equal at the beginning. Furthermore, the numbers of the host will probably not fall to a level as

low as in the preceding case, because at the point when the parasite population becomes numerically equal to it, its density will be much less, which will diminish the chance of encounters and increase the amount of residual host population. Since the residual host population is fairly large, the parasite population will not fall so far. Without following the details of the process any further it is evident that from generation to generation the variations in numbers of both host and parasite will become less marked, while at the same time the level of their populations will rise until they finally come to oscillate regularly about the same level they would have reached if the parasite had been acting on a host population already stabilised in relation to the general environment. The course of events in the two cases is very different, but the ultimate result is the same.

If the level about which the population of the pest oscillates after the parasite has had time to exert its full effect, is still above the level of economic damage, as it may be in a great many cases, the introduction of additional species must be contemplated. As we have said in a preceding section, there is a great deal of controversy in regard to this important question. The theoretical study of the problem indicates several curious possibilities, which may be briefly indicated.

Let us suppose to begin with that after an introduced species, attacking some particular stage of the host, has reached its maximum development, so that the two species oscillate more or less regularly about a certain average figure, we introduce another parasite attacking another stage. To take a simple case, let us suppose the first species attacks the larva and the second the egg, and that the egg parasite is one like *Trichogramma*, which is able to develop on several hosts, so that its attack on any one particular species has relatively little repercussion on its own reproductive powers.

During the initial period of development, the egg parasite may have no very marked effect, even though it is increasing, because a large proportion of the eggs it destroys would be killed off in the normal course of events. Eventually, however, it will begin to eliminate individuals which would otherwise have survived and would have been attacked by the larval parasite. Let us suppose its population becomes relatively stable about this time. The number of individuals of the larval parasite which succeed in finding hosts will now diminish. The number of progeny produced by the average individual of the pest will, of course, remain the same, since the

larvæ lost by the larval parasite have been gained by the egg parasite. In the following generation the number of eggs of the host will therefore be the same as if the egg parasite had not been present ; greater or less than in the preceding generation according to whether the host population is rising or falling. The egg parasite, under the conditions stated, takes approximately the same *number* as before. Now if the host population is in the descending phase of the cycle, this will mean that a greater proportion of eggs are destroyed than in the preceding generation. This will greatly increase the difficulties of the larval parasite, of which more individuals will perish, so that it will fall much below its ordinary minimum level. As the egg parasite can maintain its abundance in spite of the rarefaction of the host population, it continues in every generation to destroy the same number of eggs, and, consequently, an increasing proportion of them. The level of the host population gradually sinks. Suppose now that a sudden climatic change decimates the population of the egg parasite or favours the host so that it begins to rise. The effect of the egg parasite will then become in every generation less and less marked since the number of eggs it destroys is constant and the proportion, in a rising population, decreasing. A severe outbreak will then occur, which neither the egg parasite nor the larval parasite can check, the former because in every generation a proportion of its population overflows or is dispersed among other hosts, the latter because its population level has been greatly reduced and its increase is still checked by the influence of the egg parasite.

The effect of the introduction of the new parasite would thus be to produce violent fluctuations in the abundance of the pest, or, in other words, a series of severe outbreaks. If the average level of the pest had primarily been only slightly above the level of economic damage, the new state of affairs would obviously be worse than the first.

By a similar line of reasoning it could be shown that if two parasites attacking the same stage and occupying the same ecological niches were introduced, the effects exerted by the two considered separately, could not be added together, because the parasite with the more efficient habits would ultimately displace the other from the environment.

Without going into any more complicated cases, it is evident that the question of multiple parasitism is obscure, and that there is at least something to be said for the policy of introducing beneficial

species singly. Although the theoretical or mathematical studies on the subject can be continued indefinitely and will doubtless produce many interesting results, the most urgent need at the present time is for an exact and detailed study of the results of practical experiments combined with carefully planned research in the laboratory on particular problems. The value of theoretical considerations depends essentially upon the fundamental assumptions on which they are built up, and here, as in all other fields of science, the ultimate test of such hypotheses is the careful observation of concrete events.

If after a number of years of very careful observations, it has been determined with certainty that the increase of the parasite over the whole area has ceased and that the population present is unable to bring about the control of the host and prevent economic damage, then further steps must be taken. Nevertheless, before any further parasites or predators are introduced a very careful effort should be made to determine exactly why the species already present is insufficient to produce control. Once this is known the task of selecting another of those species known to attack the pest in its native home is considerably facilitated. Although the danger of conflicts between species with allied habits may be inconsiderable, it seems on general grounds preferable to take as the object of the next introduction, species attacking some quite different stage of the host and consequently quite unlikely to interact in any prejudicial way with the first species introduced. For example, if the species introduced has been one attacking the larval stages of the host and emerging before the pupæ have formed, the next species should, if possible, be one attacking either egg stage or the pupal stage. It may, of course, happen that the parasites attacking the particular stages may be quite inefficient in the native home, but this does not actually prove that they will be equally inefficient in the new environment. This method should therefore be given a fair trial before the introduction of species attacking the same stages of development is attempted.

10. *Summary.*

We have now covered in a very rough and general way the main phases of a practical operation in biological control. The account given has no pretension to completeness, as the special methods necessary in the case of given species may differ very greatly. However, we hope to have succeeded in making clear that the

operation of biological control is a very well defined phase of economic entomology, necessitating special knowledge, special equipment, special resources, and special methods. It is on this account emphatically a branch of economic work, in which centralisation of effort is advantageous. The present organisation of work of this type in some parts of the world has hitherto been rather prejudicial to the progress of the subject, owing to the fact that enterprises of this nature are carried on in a disconnected and uncoordinated manner in entirely different sections of the entomological services of the country concerned. The creation by the Imperial Bureau of Entomology of a central organisation, equipped with a staff and resources necessary to carry on this type of work on behalf of the different parts of the British Empire is thus expected to result in a rapid improvement in the methods employed. On the other hand, the centralisation of the work will not bear its proper fruit unless there is complete cooperation between the members of the staff dealing with the various projects and the entomologists of the Empire, on behalf of whom they are working, nor unless the operations are organised according to some coherent and intelligent plan.

The duty of the entomologist who collects and studies the material is to obtain information as complete as possible, as to the biology, habits, and methods of rearing the parasite which he collects, so that the entomologist at the receiving end is supplied with the information he requires for dealing properly with the species he receives. The duty of the entomologist who distributes the material is to keep and supply to the central organisation a complete and accurate record as to the effect produced by the parasite which has been introduced. It is gratifying to say that a number of the entomologists to whom parasites and material have been sent from Farnham House Laboratory have made an effort to supply the Laboratory with careful and accurate reports as to the condition of the material received and the results which have followed liberation. Nevertheless, the surveys that have been made up to the present in most experiments on biological control are not yet by any means sufficiently accurate and detailed. Careful studies of the exact effect produced by the introduced beneficial species are of the very greatest importance in estimating the general value of experiments in biological control, and it is not too much to say that the future progress of this work as a phase of practical economic entomology will depend mainly on the accuracy and thoroughness with which these investigations are carried out.

III. FARNHAM HOUSE LABORATORY: ITS RESOURCES, BUILDINGS, EQUIPMENT AND STAFF.

1. *Finances.*

The foundation of Farnham House Laboratory was made possible by a grant from the Empire Marketing Board of £15,000 for capital expenditure, and £25,000 to cover maintenance expenditure during a period of five years. Owing to the rapid development of the work of the Laboratory, the sum allocated for maintenance expenditure proved inadequate. In 1929, after the matter had been thoroughly discussed between representatives of the Marketing Board and the Imperial Bureau, an application for a further £2,000 per annum for maintenance expenditure was made and granted as from 1st July, 1929. In 1929 at the request of the New Zealand Government, we took over the conduct of the European end of the work on the insect enemies of New Zealand weeds, and receive from the New Zealand Government a special grant of £1,000 per annum for this work. Several members of the Australian Federal Entomological Service have been given accommodation in the Laboratory at the request of the Commonwealth Council for Scientific and Industrial Research, and payment for this accommodation is being made on a cost-account basis. In addition, a special grant of £95, for the work carried out with the parasites of certain insect pests, was made to the Laboratory in 1929, by the New Zealand Government, while similar subsidies have been offered for other pieces of work by the Governments of New Zealand, Cyprus, etc.

2. *Grounds, Buildings and Equipment.*

The grounds of the Laboratory, which comprise about six and a half acres, run north and south, with the long frontage on the Beaconsfield Road, from which they are separated by high walls and hedges. The front of the property, in which is situated the main building, is surrounded by a small park containing lawns, trees, shrubs and flower borders, of which the utility in work of a general entomological character can hardly be overestimated, since they provide a supply of plants of all kinds, to which many insects of economic importance are attracted.

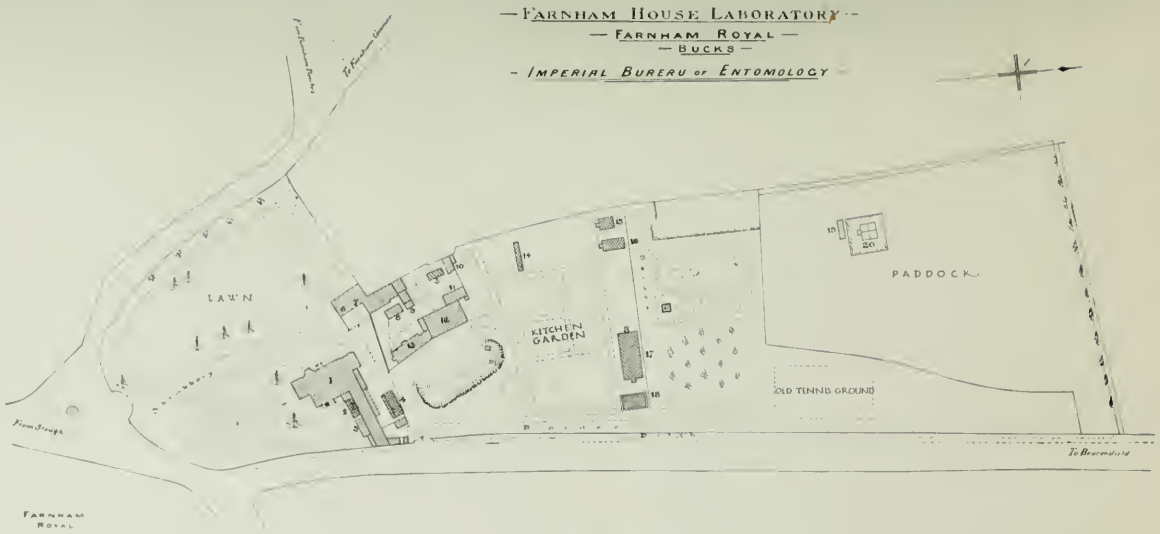
Behind the main buildings are the stables, now used as garages and store-rooms, a small greenhouse, and the cottage of the carpenter-mechanic and his wife, adjacent to which is the carpenter's shop and

a large barn. The remainder of the grounds comprises a vegetable garden of about two acres, planted with fruit trees, vegetable crops of various kinds and certain of the weeds under investigation, and in which are the four principal insectaries, situated on the south side of a high privet hedge. On the north side of this hedge is a sunken garden which contains a small pond, and is bordered on both sides by strips of uncultivated land. The extreme northern end of the grounds comprises a small grass paddock, in which animals can be kept, and an area of about two acres which was planted with forest trees of various kinds at the time the property was purchased. Adjacent to this are the filter beds and a special small insectary for work such as the breeding of Blowfly parasites, which it is not desirable to have near the main building.

The Laboratory proper is a country house, which has been admirably adapted for scientific purposes. It comprises a two-roomed cellar, an entrance hall and six rooms on the ground floor, and two upper floors, each with seven rooms. A narrow wing running from the main block to the wall separating the property from the Beaconsfield Road, contains five small additional rooms. Against the south wall of this wing are two small lean-to greenhouses.

When the building was taken over it was found that the electric light cable had not sufficient capacity to supply the current required for laboratory work. A new cable was therefore laid. As commercial gas was not available, the house was fitted with a petrol gas plant. A central heating plant was installed and radiators were provided in the various rooms, hall, passages, etc. The telephone was put in, with connections to the Superintendent's room and the upper two floors, and the telegraphic address " Entburlab " registered at the Post Office for cables and telegrams.

The modification of the premises has gone on steadily since they were taken over and is now practically complete. One of the rooms in the basement has been provided with a " baffle-chamber," lined with cement, repainted with white enamel, and the hot-water pipes passing through it covered with non-conducting material. Three electric wall heaters, thermostatically controlled and a simple apparatus for the provision of atmospheric humidity, provided with an electric hygrostatic control, which actuates an electric fan, have been installed in this room, which thus functions as a constant humidity and temperature chamber, in which these factors as well



Scale 160 ft. = 1 inch.

Plan of Grounds, Farnham House Laboratory.

1. Main Building: 2, 3, 4, 5. Greenhouses: 6, 7, 8. Garages and Stables: 9. Pump: 10. Carpenter's Shop: 11. Shed: 12. Barn: 13. Cottage: 14. Pit Lights: 15. Single Insectary: 16. Double Insectary: 17. General Insectary: 18. Storage Insectary: 19. Top Insectary: 20. Filter Beds.

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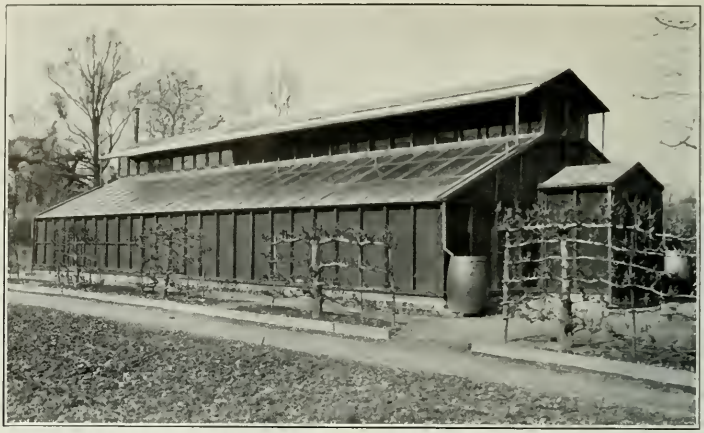


1. General Insectary in teak, with baffle chamber, ventilated central corridor and separate lateral compartments.

2. Small teak insectaries; that on the left with one, and that on the right with two compartments.

To face page 75.]

as light, can be regulated in a manner quite sufficiently accurate for practical work. Two rooms on the ground floor, three on the first floor, and four on the second floor, have been provided with teak-topped benches with drawers and sinks. Each bench is fitted with drawers, a triple laboratory tap, power and lighting plugs, necessary water supply, sealed waste-pipe and drains. Cupboards and bookshelves have been installed in all rooms. One of the large rooms on the ground floor has been fitted up as a library, two as offices for the Superintendent and the Secretary, two as store and temporary work rooms, and one as a stewards' room. In five of the rooms plate glass windows have been fitted to facilitate microscopic work.

On the first floor, one room, giving access to a convenient outdoor terrace above the library, has been fitted up as an indoor breeding room. A second has been transformed into a studio, the small window originally present having been removed, the opening enlarged to about eight feet square and a new steel-framed window, with quarter-inch plate glass inserted. The room adjacent to the studio was made into a dark-room and provided with shelves, and a very large lead-lined sink with a special photographer's tap.

In the wing running from the main building towards the Beaconsfield Road a refrigerator house was constructed by throwing the larder and dairy into one and raising the roof, inserting the necessary girder, and providing a new concrete granolithic floor. A new timber and corrugated iron enclosure was provided to accommodate the new petrol gas plant and the necessary steel gantry was erected in conjunction therewith. The heating apparatus of the leanto greenhouses was later found to be defective, and as one of these was needed for practical work, a system of electric heaters was installed.

Four insectaries were originally constructed (Plate VI). Three of these were built of teak, with phosphor-bronze or copper gauze sides; the other, which is chiefly used as a shelter or hibernating shed, of deal. One of the teak insectaries, situated in the upper part of the garden, has a wooden roof, the remaining two are roofed with "Vita" glass, which admits a high proportion of ultra-violet rays, in order to make the lighting as natural as possible. Of the two original teak insectaries, with "Vita" glass roofing, one has only a single long compartment, while the other is divided into two.

In view of the rapid development of the work, it was soon found that the insectary and greenhouse space was quite inadequate. In the early part of 1929, plans for a large insectary were therefore drawn up. This insectary (Plate VI) is constructed like most of the others, of teak, with sides of fine meshed copper gauze and a "Vita" glass roof. It consists of ten lateral compartments, opening by means of double doors into a central corridor, at the end of which is a baffle chamber. Above the central corridor is a ventilating chamber with gauze sides and overhanging eaves, constructed in order to prevent the development of excessive temperatures during the summer months. In order to permit of the breeding of tropical pests and beneficial insects, even under English winter conditions, the four compartments, situated at the end away from the door, the end of the corridor, and the end and sides of this part of the ventilating chamber, have been fitted up with detachable "Vita" glass sashes. Three rows of four inch pipes have been run round the inside of the compartments, which are heated by a greenhouse boiler, bricked into the end of the corridor. At present coke is used for heating, but as soon as a suitable oil burner is obtainable, this method of heating will be employed, since it can be used in connection with a thermostatic control, thus giving a constant temperature in the heated portion of the insectary.

Each of the compartments of the insectary is ten feet square, five feet high on the outside, and ten feet high on the side next to the corridor. In each compartment there is a cement trough two feet deep and two feet nine inches wide, surrounding a cement platform four feet by four feet nine inches with raised sides. This trough is filled with sand or sterilised soil, so that any plants or trees required can be grown under conditions as natural as possible.

The corridor and each of the compartments are provided with wall plugs and droplights, and in the four heated compartments, power plugs have also been installed. A power cable connects the insectary with the meter at the main building. A tap for water, connected with the main, has been provided in the end of the corridor.

In spite of this new building, the space provided for breeding work is still insufficient, and an additional small building may have to be erected for the breeding work on the Codling Moth parasites early this season.

An effort has been made to provide in the laboratory an equipment as efficient and up-to-date as possible.

Three automatic Hearson incubators, and an automatic Hearson refrigerator were purchased at an early date. Two special Wisconsin Cabinets constructed on the lines of those designed by Mr. R. H. Stoughton, of the Rothamsted Experiment Station, and permitting of a very accurate regulation of temperature, humidity and light, have been constructed by the Laboratory Carpenter, Mr. J. W. Smith, and fitted up with the necessary heaters, humidifiers and controls. A special apparatus for the regulation of humidity and temperature, in relation to small insects, was constructed for Mr. MacLagan in his work on *Smynthurus*. Finally, some eighty-five cages, built of teak, with copper gauze sides, and, for the most part, "Vita" glass tops and doors, of most excellent construction, and in a great variety of sizes and designs, have also been built by Mr. Smith. A considerable number of thermographs, hygrothermographs, Livingston atmometers, and thermometers of various types, including a standardised instrument, have been purchased for use in connection with certain phases of the work.

Two excellent cameras, one of the most recent type, are available for outdoor work, and another for high-power work in the Laboratory. The optical equipment also includes two compound microscopes (Swift and Zeiss) and six Zeiss binocular microscopes. An autoclave, fitted for electric heating, has been installed for bacteriological work, and a Brunsviga Calculating machine and a Dictaphone have also been purchased.

In spite of the close proximity to London, and the unusual facilities available at the Publication Office of the Bureau, a well-stocked local library is essential to the proper conduct of the investigations carried on at the Laboratory, especially since, as will be clear from the remarks in the second part of this report, the reference works required necessarily cover a much wider field than is usual in entomological libraries. At present, the Laboratory library comprises more or less complete sets of about twelve periodicals, about 150 reference works, and a collection of about 2,000 separates, including a large number of the bulletins of the United States Bureau of Entomology, obtained through the kindness of Dr. L. O. Howard, as well as a number of duplicates transferred, with the kind permission of Dr. S. A. Neave, from the library of the Publication Office.

The present Superintendent wishes to take this opportunity of expressing his appreciation of the excellent judgment and technical ability shown in the fitting up and in the equipment of the Laboratory,

carried out under the direction of Dr. Neave. The fact that this work had, for the most part been completed before the present Superintendent took charge has greatly facilitated the organisation of the work.

3. *Staff.*

A number of changes in the staff of the Laboratory have occurred since its foundation. During the initial period the activities of both the Laboratory and the Publication Office were directed by Dr. S. A. Neave. Mr. R. A. Stenton and Dr. J. G. Myers were appointed as entomologists, Miss R. N. Davenport was transferred from the Publication Office for the secretarial work, Messrs. L. F. Milton and D. Berryman were engaged as laboratory stewards, Messrs. P. Trevaskis and H. Macro as gardeners, and Mr. and Mrs. J. W. Smith as carpenter-mechanic and caretaker, respectively. Owing to the rapid increase in work in both fields and the distance between the two offices, this arrangement was found to be impracticable. Dr. Neave therefore withdrew from the Laboratory on June 9th, 1928, on which date the present Superintendent took over. The resignation of the Senior Entomologist, effective on August 31st, the transfer of the former Secretary, Miss R. N. Davenport back to the Publication Office, and the resignation of the former Head Laboratory Steward, Mr. L. F. Milton, occurred about the same time. Finally, on October 27th, 1928, Dr. J. G. Myers left for Trinidad in order to investigate, on behalf of the Laboratory, the possibilities of applying the methods of biological control to the pests of the British West Indies and adjacent territories.

Owing to the difficulty of obtaining men with the ability and training necessary for the work, it was some time before the vacancies could be filled. Dr. G. Salt was appointed as Senior Entomologist to replace Dr. Myers in the autumn of 1928, and took up his duties on December 1st of that year. Dr. W. H. Thorpe was appointed on November 15th, 1929; Mr. H. T. Rosenberg was taken on in a temporary capacity on August 13th, 1928, and was given a permanent appointment on August 1st, 1929. Mr. R. C. Jeffery was appointed as Secretary to replace Miss Davenport on July 16th, 1928, but the services of Miss Davenport were retained by special arrangement with Dr. Neave, for work on the library, the parasite catalogue and bibliographies, to which she devotes one day a week. Mr. E. Basden was appointed as additional Laboratory Steward. The Head Gardener,

Mr P. Trevaskis resigned, to take up a position in Australia, on September 14th, 1929, and was replaced by Mr. J. G. Grant. The second Gardener, Mr. H. Macro, after a prolonged absence through illness, was discharged on August 19th, and replaced by Mr. S. W. Burrows.

The taking over of the work on the insect enemies of noxious weeds also necessitated new appointments. This work was at first in charge of Dr. A. S. Watt, who was appointed as Botanist to the Laboratory on May 1st, 1929, but resigned to take up the post of Lecturer in Forest Botany in the University of Cambridge. He was replaced by Mr. E. H. Chater, who took up his duties on November 1st, 1929, and is assisted by Mr. E. Cameron, appointed in a temporary capacity as from September 27th, 1929.

Since the work on which the Laboratory is engaged renders it necessary to have collectors permanently in the field, two entomologists, Mr. P. de Rippas and Mr. S. Kozlovsky, were appointed as Field Agents in France as from July 1st, 1928, while Mr. H. S. Hanson was appointed as Field Agent for the British Isles on September 23rd, 1929.

Mr. D. S. MacLagan, a Scholar of the Ministry of Agriculture for Scotland, was given accommodation at the Laboratory at the request of the Ministry, during the first two years of his Scholarship, and has been engaged in research work on the *Smynthurus* problem from October 1st, 1928, to the present time. Valuable gratuitous assistance was also rendered in 1928 by Mr. F. Muir, Consulting Entomologist to the Hawaiian Sugar Planters' Association, by Mr. G. H. Spooner and Mr. H. Wood of the University of Cambridge in connection with the Pine Shoot Moth work, as well as by Mr. B. Uvarov, who was given a temporary appointment for six weeks in 1928, on the Sheep Blowfly work, and by various temporary workers from the village of Farnham Royal, amongst whom, Miss R. Thorne deserves special mention. A temporary assistant to the Laboratory Steward was employed for a few months in 1927.

4. *Summary.*

Work on biological control is in many ways peculiarly difficult, demanding special knowledge of several extremely difficult groups of insects, and an intimate acquaintance with certain very delicate technical methods. It is emphatically rather a field for the specialist than for the ordinary economic entomologist, who has usually neither the time nor the resources to handle it in a satisfactory manner. It

is, therefore, very important to have within the Empire a centra organisation capable of co-ordinating research, investigating funda mental problems, and providing practical assistance and advice i regard to the method of biological control.

The situation of the Imperial Bureau of Entomology is in thi respect exceptionally favourable. As has already been pointed out movements of insect pests occur between all countries of the globe Nevertheless, Europe is the mother of Western Civilisation. The basi foodstuffs of Europe are of fundamental importance to its colonies The insect pests of the plants and animals utilised in Europe are therefore, amongst the most important in relation to the agricultur of the Empire. The fact that the United States Bureau of Entomology maintains permanent laboratories in Europe for the study of th parasites of the introduced European insects, and that a number o important Canadian, Australian and New Zealand problems have had to be taken up in Europe, is sufficient proof of this contention.

The investigation of European insect pests, accidentally introduced into the British Dominions and Colonies, will always thus be one o the primary functions of any organisation designed to centralise and facilitate work in biological control within the Empire. Such studies and the practical work to which they lead, could, of course, be carried on by agents sent specially to Europe for the purpose. There are no doubt, cases in which this would be desirable, and in any event an exchange of staffs between the Laboratory and the Dominion Entomological Services is to be recommended as giving opportunity for personal contact and first-hand acquaintance with conditions in the various parts of the Empire. In general, however, it is quite certain that a permanent central staff, trained in the special methods of biological control, and familiar with European conditions, languages and customs, can carry out the investigations required by the entomologists of the Empire immensely more efficiently, rapidly and cheaply than agents sent specially to Europe for the purpose. In many cases the price of the return passage alone would more than meet the total cost of the work, and the time required for the journey would carry the project well on toward a point where the desired results could be obtained by relatively untrained assistants. The plan here advocated provides for a number of special field agents or entomological scouts working in small and essentially temporary sub-stations, situated in the principal bioclimatic areas of Europe. A mobile and flexible organisation of this kind, which is absolutely

necessary for the best results, is in a much better position to seize opportunities for practical work when they occur (and their incidence can never be predicted with certainty) than agents sent specially from distant points, who, because of their unfamiliarity with the region or because of some seasonal irregularity, arrive too late to obtain the desired material.

In many cases, even though the pests giving trouble in a colony have not come from Europe, their original home is in some region which can be reached as rapidly, or more rapidly, by way of Europe, than by any other route. In that event the Laboratory can always act as a relay station for parasite material passing through. This is especially desirable when the insects transmitted have to be fed or allowed to reproduce en route, for the absence of facilities of this kind has in the past led to the total loss of consignments of beneficial insects, gathered with great labour and at great expense.

Furthermore, the introduction of the native parasites or predators of introduced pests from the native home is not by any means the only phase of biological control which is of practical importance. The work in California on the ladybird attacking the citrophilus mealy-bug, and in England on the White-fly parasite, to which reference has already been made, shows clearly that it is in some cases possible to increase the efficiency of an existing beneficial insect by artificial methods, and the investigations carried out at the Laboratory and elsewhere on Trichogramma have also given very promising results. The special facilities possessed by the Laboratory easily permit an extension in its activities to cover problems of this kind.

In addition to all this, it is imperative that the Laboratory carry out research into some of the fundamental problems of biological control, which cannot be conducted to the best advantage until the causes of the insect outbreaks and the natural control of pests are better understood.

IV. THE PRACTICAL WORK.

In the preceding sections an account has been given of the organisation and possibilities of work on biological control, with special reference to the organisation and equipment of Farnham House Laboratory. The next section will give an account of the various practical operations undertaken up to the present time, with indications

regarding the methods which have been employed in particular cases, and the results which have been obtained to date. The projects taken up have been classified under the groups of economic plants and animals, attacked by the pest studied. At the end of the section there has been included a table in which the projects on hand are grouped according to the various parts of the Empire interested.

1. *Parasites of Deciduous Fruit Insects.*

The Codling Moth (*Cydia pomonella* L.).

The Codling Moth is the most important insect pest of the apple. It originated in Europe, and is now distributed over practically all parts of the world where apples are grown. The losses from this insect in the United States alone are estimated to amount to over £3,000,000 per annum. It attacks the apple, pear, quince, English walnut, crab apple, and wild plum. The injury caused by the Codling Moth in many districts is so great that it is practically impossible to obtain satisfactory crops without applying arsenical sprays several times during the season. So large is the amount of poison which has to be applied to the apples in some regions that special arrangements are necessary to remove it from the fruit and in some instances the presence of arsenical residues has created serious difficulties in marketing.

In view of the importance of this pest, it has been decided to make a thorough investigation of its parasites, more particularly as it is an insect of European origin. This work was carried on during the first season by Mr. P. de Rippas and Mr. S. Kozlovsky in North-Western France, and continued during 1929 and 1930 by Mr. Kozlovsky in all of the important apple-growing regions of France. Collections of hibernating Codling Moth larvæ and parasites were made in fifteen localities situated in nine of the principal apple-growing departments. Eighty-nine consignments, containing approximately 33,550 larvæ were sent in, together with eleven consignments of parasitic cocoons. The examination of this material is not yet completed, but up to the present date the following eleven species of parasites have been obtained :—

Ichneumonidæ ..	*Trichomma enecator*, Rossi.
	Pristomerus vulnerator, Panz.
	Ephialtes extensor, Tasch.
	Hemiteles hemipterus, F.
	Hemiteles cingulator, Gr.

Braconidæ	..	*Ascogaster 4—dentatus*, Wesm.
Chalcididæ	..	*Eupelmus urozonas*, Dalm.
		Perilampus laevifrons, Dalm.
		Dibrachys affinis, Masi.
Tachinidæ	..	*Arrhinomyia tragica*, Meig.
		Exorista westermanni, Zett.

Hemiteles hemipterus, H. cingulator, Perilampus laevifrons and *Dibrachys affinis* are probably all hyperparasites. The status of *Eupelmus urozonas* is at present doubtful. All of the other species are primary parasites.

It is very difficult to collect in the field, numbers of Codling Moth larvæ sufficient to provide really large colonies of the parasites. For this reason we have decided to increase the numbers of parasites we wish to export by intensive breeding methods. This work has been placed in charge of Mr. H. T. Rosenberg.

The first species chosen for breeding work was one discovered some years ago attacking the Codling Moth in the United States. It was believed by the American entomologists to be a native species and described by Viereck under the name of *Ascogaster carpocapsae*. This parasite deposits its egg in the egg of the Codling Moth and emerges from the full-grown larva. It has several generations a year and in certain regions of the United States destroys a relatively high percentage of the Codling Moth larvæ.

As has already been mentioned, a few specimens of a Braconid parasite belonging to the same genus, *Ascogaster quadridentatus*, Wesm., were obtained in 1929 from the collections made in Northern France. These have been compared by Dr. Ferriere with specimens of *A. carpocapsae*, Vier., from the United States, and have been found to be the same. It thus appears that this parasite is really one of the native enemies of the Codling Moth, which has probably been introduced into America in the hibernating larvæ of the host insect.

So far, *Ascogaster quadridentatus* has been rather rare in our material. However, thanks to the kind assistance of Dr. A. L. Quaintance of the United States Bureau of Entomology, we obtained from Mr. E. J. Newcomer of his Division, in the winter of 1928–29, some 2,200 hibernating larvæ of the Codling Moth, of which some 200 were believed to be parasitised by *Ascogaster*. A satisfactory number of both moths and parasites was obtained, and after a number of experiments, a method was devised

by Mr. Rosenberg, for obtaining a continuous supply of eggs of the Codling Moth, which was reared artificially in the Laboratory throughout the summer. As the Codling Moths emerged, they were placed in large cardboard cylinders lined with white or black paper, and having the ends covered with sheets of cellophane, attached by india-rubber bands. The moths were supplied with a small amount of food in the form of honey water and deposited their eggs freely upon the paper lining the cages and upon the cellophane. The pieces of paper bearing the eggs were then cut out and placed upon apples arranged in large trays, and it was found that they hatched quite successfully and were able to penetrate into the apples. After the end of the breeding period the larvæ of the Codling Moth emerged from the apple and pupated in layers of corrugated paper arranged around the trays, which were covered with fine-meshed wire gauze in order to prevent the escape of the caterpillars. In this way, it was found possible to rear the Codling Moth with great success in the Laboratory.

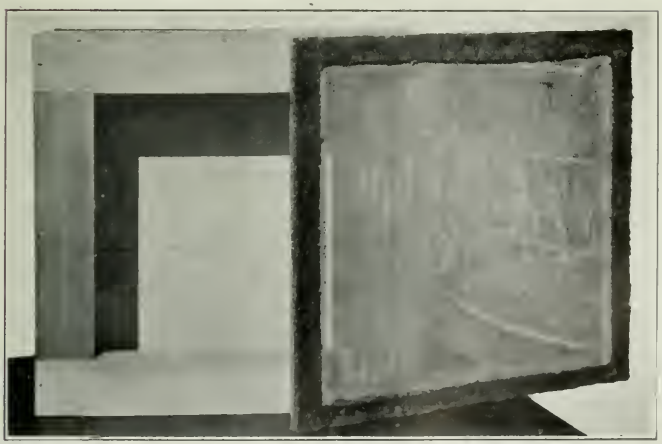
In order to rear the parasites the bits of paper bearing the eggs were placed in cages with the females, which oviposited freely in them. These eggs were then placed, like the unparasitised ones, on apples, in which the larvæ completed their development. A large stock of this parasite is now on hand, and the breeding work in connection with it will be continued during the course of the present season.

During the winter of 1929–30, Mr. Rosenberg has continued his experiments with other species and has already succeeded in breeding *Ephialtes extensor* in the laboratory. It is hoped that in the near future it will be possible to distribute stocks of the most important parasites to regions where the Codling Moth is injurious. A supply of several races of the egg parasite *Trichogramma*, which is being reared in large numbers in many parts of the world, with a view to its use as a control for Codling Moth and other Lepidopterous pests, is kept permanently at the Laboratory, together with a complete set of the apparatus used for rearing this parasite.

The Woolly Aphis (*Eriosoma lanigera*, Hausm.).

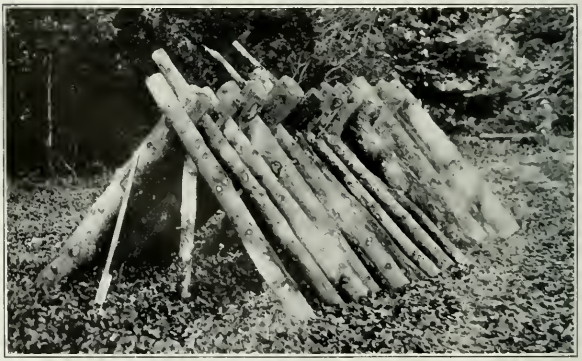
The Woolly Aphis of the Apple, sometimes known in England as "American Blight," is a very injurious pest, which perhaps originated in North America and has now spread practically to all parts of the world where apples are grown. Even in America it

1. Rearing of Codling Moth parasites: Oviposition cage for Codling Moths, consisting of a cardboard cylinder with a removable paper lining, closed at the ends with cellophane and mounted on a wooden block.



2. Modified Fiske Tray in deal, with cloth bottom and detachable cover of wire gauze on wooden framework, with felt strip.

1. Rearing of *Aphelinus mali ;* left, young apple tree from insectary with Woolly Aphis heavily parasitised by *Aphelinus ;* right, young apple tree from out-doors, adjacent to insectary with neither Woolly Aphis nor parasites.



2. Collection of *Sirex* parasites : Stack of logs infested by *Sirex* larvæ, constructed for the attraction of the parasites *Rhyssa* and *Ibalia*. The dark rings indicate *Sirex* tunnels.

To face page 85.]

is an insect of considerable economic importance, but its destructiveness is to some extent reduced by a number of parasitic and predaceous enemies which prey upon it, and of which the most important, judging from the available data, are the Syrphid, *Pipiza pisticoides*, Will., whose larvæ are predacious, and the Chalcid, *Aphelinus mali*, Hald., which is, in the early stages of its development, an internal parasite of the aphid.

In order to reduce the injury due to the Woolly Aphis, the entomologists of the apple-growing regions began, a number of years ago, to introduce *Aphelinus mali* from America, the material having been provided in most cases, if the writer is not mistaken, by the U.S. Bureau of Entomology, though a successful shipment to South Africa was made in 1923 by A. E. Lundie, to whom we owe a very valuable monograph on the biology of this parasite. The results obtained were in several cases strikingly successful ; as, for example, in certain parts of New Zealand, throughout which it was energetically distributed by Dr. Tillyard.

In 1919, at the request of Dr. Paul Marchal, a shipment of *Aphelinus mali* was sent to France by the U.S. Bureau of Entomology. These specimens did not survive the journey. In 1920, a second consignment of the parasite was brought to Europe by Dr. L. O. Howard, and from this material numerous individuals of *Aphelinus* were obtained and distributed throughout France.

In 1922, a consignment of this French material was obtained from Dr. Marchal by Mr. J. C. F. Fryer, Entomologist to the Ministry of Agriculture, who has since reared it at Harpenden for distribution throughout the British Isles.

In view of the importance of the Woolly Aphis to the apple-growing regions of the Empire, and the possibility that consignments of its parasites would be requested, it was considered desirable to maintain at Farnham Royal a colony of *Aphelinus mali*. Through the kindness of the Ministry of Agriculture a stock of the species was obtained in the summer of 1927 from Harpenden, and is still flourishing.

The colony of Woolly Aphis was obtained by attaching twigs, infested with the pest, to the branches of standard apple trees, from six to eight feet in height, planted in fourteen inch pots, which were placed in an insectary with a " Vita " glass roof and sides of fine mesh phosphor-bronze gauze, and buried to the rims in sand. The

apple trees used were three " Queen Mary," two " Beauty of Bath," two " Lord Derby," and one " Newton Wonder." The apple trees were watered regularly, but were, of course, protected from rain. No other enemies of the Woolly Aphis were introduced and though occasionally an adult ladybird or Syrphid has been observed in the compartment, none of these stray invaders have ever increased in numbers.

Twigs having parasitised aphids have been removed from time to time for the purpose of making shipments, others bearing unparasitised colonies have been added on several occasions when it appeared that there was some danger of extermination of the host by its parasite. On the whole, however, the interference with the progress of events has been relatively slight.

The breeding experiment is thus of considerable interest, in that it gives an idea of the limitations of *Aphelinus mali* as a parasite of the Woolly Aphis, under the conditions prevailing in the insectary. At the end of the third season the apple trees in the insectary are still heavily infested with the Aphids, the two " Lord Derbys " being in an exceptionally bad condition. None of the apple trees in the grounds of the Laboratory, including a number of standards in pots adjacent to the insectary, show, at present, any signs of the presence of Woolly Aphis. The photograph (opposite p. 85) of one of the trees outside the insectary beside one of the more heavily infested specimens from inside, will give a very fair idea of the present state of affairs.

A careful examination of the colony in the insectary was made during the early part of October, 1929.

In spite of the fact that the *Aphelinus* had had almost the whole of three seasons to reproduce at the expense of its host, less than 50 per cent. of the individuals present contained larvæ of the parasite. In 77 parasitised individuals examined there were actually present 93 eggs and larvæ of *Aphelinus*. Had these been distributed singly within the hosts the percentage of parasitism would have been about 10 per cent. higher than it actually was.

Up to the date of this report a total of fourteen consignments of Woolly Aphis, parasitised by *Aphelinus mali*, have been despatched from Farnham Royal. Of these, two were sent to Kenya Colony, one to Poland, one to India (Saharanpur, U.P.), and the remainder to various points in England.

In view of the unsatisfactory results obtained with *Aphelinus mali* in England, an attempt has been made to obtain from America, a colony of the Syrphid, *Pipiza pisticoides*, considered by Metcalf and Patch as the most important enemy of the Woolly Aphis in the North-Western United States, but up to the present no material of this species has been received.

Pear Slug (*Caliroa cerasi*, L.).

The Pear Slug, first described by Reaumur in 1742 under the name of " fausse chenille tetard," is an insect which is apparently native in Europe, but which is now distributed throughout the greater part of the world, being recorded from Canada, the United States, South America, Australia, New Zealand and Japan. It feeds almost exclusively on Rosaceous plants, the most common hosts being Pear, Cherry, and Plum, though plants belonging to other families are occasionally attacked. The damage is produced by the larvæ, which feed upon the upper surface and interior tissue of the leaves of their host plants causing a loss of assimilation surface and sometimes complete defoliation.

Although the Pear Slug can be easily controlled by arsenical and other sprays, it may, if untreated, be quite destructive. In New Zealand, it is often quite injurious, particularly, according to Thomson (1922), in the North Island, where it practically prevents the use of hawthorn as a hedge plant. In certain parts of Australia it is also rather destructive. Owing to the injury occasioned by it in New Zealand, an attempt to introduce its parasites was made in 1922 by Dr. Tillyard, with the help of Dr. A. D. Imms of Rothamsted, but this was unsuccessful.

At the request of Dr. Miller of the Cawthron Institute, Nelson, New Zealand, and of the State Entomologist of New South Wales, and Western Australia, a further attempt to procure and establish the parasites of this species is now being made. The results of the work will, it is hoped be published in detail in the near future by Mr. Rosenberg ; so that only a general account of the methods used and the results obtained will be given here.

Owing to various unavoidable delays the field work on the Pear Slug was not begun until the middle of July, 1928, when two collectors were appointed and assigned to the project in France. After numerous preliminary inquiries it was decided to confine investigations to the region between the neighbourhood of Paris and the coast.

Collections were made in some fourteen localities in the Departments of Calvados, Ille et Vilaine, Oise, Seine et Oise, and Seine et Marne, from about the middle of July until the end of the first week in October. A total of about 50,000 larvæ was collected in Northern France, the great bulk of the material from the environs of Caen in the Department of Calvados, where over 40,000 larvæ were obtained. In addition, about 1,800 larvæ were collected by Mr. Rosenberg in England at Bradwell on Sea in the County of Essex.

As soon as possible after collection, and usually on the same day, the larvæ were placed on the leaves on which they were gathered, in cylindrical brass containers measuring about 3 inches in diameter by five and a quarter inches in height, provided with three oval openings, measuring about two inches in diameter by four inches in height, and covered with a fine mesh brass wire gauze. These containers were posted individually to the Laboratory in stout cardboard mailing cases, just large enough to hold one of them. Immediately on receipt of the material, it was unpacked and provided with food and placed in cold storage until suitable arrangements could be made.

Sample lots of the larvae were dissected from practically all the consignments received and it was found that at least two species of parasitic Hymenoptera and one Dipterous parasite were present. In the localities in which high parasitism was observed, the infestations were, on the whole, quite negligible. The greater part of the collecting had to be done at Caen, in spite of the fact that the percentage of parasitised larvæ in that district was relatively low.

The work of rearing the larvæ of the Pear Slug proved to be somewhat more difficult than was anticipated and a considerable number of larvæ was lost before suitable methods were involved. These various difficulties were finally solved by transferring the larvæ one by one as soon as possible after receipt, to pear twigs whose leaves were kept fresh by standing them in a bottle of water, which was placed in a tray filled with clean sterilised loam. Some days after the last of the larvæ had descended the loam was sifted and the cocoons removed. Those which were defective were left for purposes of dissection, the others were placed in earth in perforated zinc boxes, lined with copper gauze and buried in the ground out-of-doors, where they were allowed to remain during the winter. The

majority of the cocoons were used for shipment, but some were retained for rearing. The following four species of parasites were obtained, all Ichneumonids.

Mesoleius caninae, Bridgm.
M. dorsalis, Grav.
Polyblastus phygadeuontoides, Kr.
Perilissus luteolator, Gr.

No specimens of the Dipterous parasite were reared. Some adults which emerged were preserved for the Laboratory collection and the remainder were placed in an outdoor insectary with the emerging adults of the Pear Slug, and a small number of pear trees and wild plum trees in pots, in the hope of obtaining a heavily parasitised lot of Pear Slug larvæ. The Pear Slug oviposited extremely freely in captivity, and very soon the great majority of the leaves of the pears in the insectary were dotted with eggs. About 60 to 70 per cent. of these died in the leaves owing to the overheated condition of the greenhouse. This was especially noticable among the eggs which were placed in the leaves immediately underneath the "Vita" glass roof of the insectary, the great majority of which dried up without hatching, although the leaves in which they had been placed did not seem to suffer in any way. Most of the eggs deposited were placed in the leaves of the pears, very few being deposited in the leaves of the wild plum. In spite of the heavy mortality among the eggs, many larvæ developed, so that most of the leaves were completely destroyed by the time the slugs had completed their development. Nevertheless, a relatively small number of cocoons was obtained from the earth beneath the pear trees, and in samples of these dissected very few parasites were found. The experiment, therefore, cannot be regarded as a success, but the results are encouraging, and it is considered that with suitable modifications the method can be made to yield a very large supply of parasitised Pear Slug cocoons.

Owing to the urgent demand for this material it was decided not to wait until the spring before shipping the material, and consequently two shipments were prepared. One containing 6,524 cocoons was shipped to Dr. Miller of the Cawthron Institute in December, 1928, while the other containing 6,330 cocoons was

given on October 20th to Mr. W. B. Gurney, State Entomologist for New South Wales, who took it to Australia under his personal supervision. The complete reports as to the results obtained from the shipments have not yet been received.

The Hazel-Nut Scale (*Lecanium coryli*, Ledgr.).

The Hazel-Nut Scale, *Lecanium coryli*, is an insect, belonging to the group of the Coccids. It is widely distributed throughout Europe, of which it is a native. It attacks a great many species of plants, and is sometimes extremely injurious, as for example in certain parts of Russia, where special measures have to be taken to combat it owing to the injuries it has caused to plums. It was accidentally introduced into British Columbia in 1903, probably on shade trees from England, and in the absence of any natural parasite has increased enormously. It is now seriously injurious to maple trees in Vancouver, causing the leaves to shrivel and drop prematurely. In the autumn of 1924, it was found that practically all the shade trees lining some twenty-five miles of boulevards in the west end of Vancouver, as well as maple trees in parks, were badly infested. In view of the severity of the infestation, parasites of this insect were requested by the Dominion Entomologist of Canada, as soon as the Laboratory was founded. The parasites and predators of *Lecanium coryli* had previously been studied by Silvestri (1919) and Imms (1918). It was, therefore, not necessary to carry out any extensive biological studies of the insect. On the other hand, owing to the fact that the distribution of the insect is somewhat irregular some difficulty was at first found in obtaining a sufficient quantity of material for parasite work. The first supply was obtained from Professor Newstead, F.R.S., in June, 1927, and an attempt was made to establish a colony of the scale and one of the parasites in an insectary, but this attempt was a failure. Accordingly, a new supply was requested from Professor Newstead, who forwarded it early in 1928. This material was placed partly in an insectary and partly in indoor breeding cages, and from it was obtained a considerable number of Chalcid parasites belonging to several species, together with a large quantity of the larvæ of the Scale. Branches of hawthorn were placed in the cages with the emerging larvæ and soon became covered with them. The branches were then transferred to the insectary and placed among the branches of young hawthorn plants in pots. Following the policy outlined in the previous chapter, it was decided to send out first only

one parasite of *Lecanium*, and for this purpose the large and important species, *Blastothrix sericea*, was selected. About 300 specimens of this Chalcid emerged during the month of June, and these were sent to Mr. A. B. Baird, in charge of the Dominion Parasite Laboratory at Chatham, Ontario, in two shipments, one on June 29th and the other on July 5th. The parasites were sent in cold storage, in glass tubes, with raisins as food. They were trans-shipped by Mr. Baird to Vancouver, where they arrived with the loss of very few individuals, and were liberated in the neighbourhood of the city. The attempt to start colonies of the scale and its parasites on the hawthorn in an insectary was believed at first to be unsuccessful, but during the course of the ensuing winter numerous individuals were found to be present on the plants. Samples were dissected and many were found to be parasitised by *Blastothrix sericea*, which had been liberated in the insectaries at the same time as the scale. These emerged during the spring and again attacked the scale, which resulted in a considerable increase in the number of parasites. A total of 1,250 scales was eventually obtained from this experimental colony, of which the great majority was parasitised, and these were shipped to Canada early in June. In the meantime a number of collections of the scale were made in the Midlands by Mr. Wadsworth of the University of Manchester, and placed in rearing cages at the Laboratory. From these we obtained a total of about 766 adults of *Blastothrix* which were shipped to Canada in July, and then trans-shipped from Chatham to Vancouver like the preceding shipments. All of this material arrived in good condition. The larvæ obtained during the time the parasites were hatching were again placed upon hawthorn in the insectaries. Thousands of scales are now present. These will be used as a basis for further attempts to rear the parasite in large numbers in the insectary and will be sent to Canada during the course of the summer.

The Oriental Peach Moth (*Cydia molesta*, Busck.).

The Oriental Peach Moth is an insect of Japanese origin, closely allied to the Codling Moth and almost equally destructive in certain regions. It is distributed over a considerable part of the United States, where it was first discovered in 1916, and has also spread to the fruit-growing regions of Southern Ontario. It attacks plum, peach, cherry, apple and quince. The larvæ of the first generation attack the growing tips of the branches, destroying a large proportion

of the terminal buds, and bore into the tender shoots. The later generations burrow through the fruit, causing it to decay, and also burrow into the more mature twigs. It also exists in Australia. A number of years ago the Oriental Peach Moth became established in the French and Italian Rivieras. The French and Italian entomologists who studied the insect found it was sometimes attacked by the native parasites of various species. The Dominion Entomologist of Canada therefore requested us to investigate the European parasites of the Peach Moth, in the hope of finding some which would be useful in controlling this pest in Canada. Mr. de Rippas was detailed to this work at the beginning of 1929 and continued it throughout the whole season, working partly in the region of Antibes in France, and partly on the Italian Riviera, where he made his headquarters at Chiavari, at the Pathological Laboratory directed by Dr. G. Paoli. Thanks to the help of Dr. Paoli and his assistants, Mr. de Rippas was able to carry investigations of the parasites of the Peach Moth in a great number of different localities. Owing to the fact that the work was not undertaken until rather late in the season, considerable difficulty was found in obtaining a sufficient quantity of the material for the work. However, a very fair idea of the parasites attacking the Peach Moth in the Mediterranean zone was obtained from the specimens collected. Four parasites, which seem to be primary parasites of the Peach Moth, were reared. The most important of these is *Pristomerus vulnerator*, Panz., while *pomorum*, *Pimpla Ascogaster 4-dentatus*, and a Tachinid, which seems to belong to the genus *Actia*, were also reared. All of these are, of course, species which are normally parasitic on other European insects, and more especially on Micro-Lepidoptera. *Pristomerus vulnerator* and *Ascogaster*, the most important parasites collected, have been found to be parasitic in Northern France, on the Codling Moth, from which they can probably be collected more easily than from the Peach Moth. The United States Bureau of Entomology have now detailed one of their investigators to this work. He is located at Antibes in Southern France and will work during the coming season in co-operation with Mr. de Rippas.

The Leaf-Curling Pear Midge (*Dasyneura pyri*, Bouché).

This insect is generally distributed throughout Northern and Western Europe, where it attacks all varieties of pears, and seems, in general, to be of no importance ; but in New Zealand, where it was accidentally introduced a number of years ago, it has done a great deal of damage

in the pear-growing districts, attacking all commercial varieties. In 1925, investigations of the parasites of the Pear Midge in Europe, were begun by Dr. R. T. Fisher and Dr. J. G. Myers, working under the direction of Dr. Marshall. Four consignments of parasitised material were shipped by Dr. Fisher and Dr. Myers to New Zealand in the summer and autumn of 1925. From these consignments a considerable number of specimens of *Misocyclops marchali*, Kieff., one of the most important of the parasites, was obtained and liberated in some of the infested districts. In 1928, the Entomologist of the Cawthron Institute reported that the parasites had since become abundant in the infested areas, from some of which satisfactory crops had been obtained for the first time for many years.

In addition to the insects mentioned above, investigations were begun in the summer of 1928 on the Apple Bud Moth (*Eucosma ocellana*, Schiff.) and the Apple Sucker (*Psylla mali*, Schmid). Investigations of the natural enemies of the Peach Twig Borer (*Anarsia lineatella*, Zell.), the Queensland Fruit Fly (*Dacus ferrugineus*, Fabr.), the Bronze Beetle (*Eucolaspis brunnea*, Fabr.), and the Australian Apple Leaf Hopper (*Typhlocyba australis*, Frogg.) have also been requested.

2. *Parasites of Forest Insects.*

The Pine Shoot Moth (*Rhyacionia buoliana*, Schiff.).

The Pine Shoot Moth is a small moth, very widely distributed throughout Europe, where it causes, in certain seasons, severe damage to pine. It has been accidentally introduced into the United States and Canada, where it is now a rather serious pest in certain districts. In view of the damage caused by this species in Southern Ontario, we were asked in 1927 by the Dominion Entomologist to investigate and collect any parasites likely to be useful in checking its ravages. In the summer of 1928 a heavy infestation by the Pine Shoot Moth was reported from one of the Forestry Commission's plantations in Norfolk and this was immediately investigated. These revealed the presence of a number of parasites, and arrangements for large scale collections were at once made.

With the permission of the Forestry Commission, employees in the district were detailed to the work, and in the course of about a couple

of weeks about 100 bags of infested material, estimated to contain 100,000 infested shoots were gathered and despatched to the Laboratory. Very careful preliminary studies of the material were made with the help of Mr. Spooner and Mr. Wood of the University of Cambridge. In order to obtain information as to the status of the various parasites and their relative importance as controlling factors of the Pine Shoot Moth, part of the material was placed in incubators at relatively high temperatures in order to accelerate the development of the parasites, so that they could be identified before the material had reached its destination. In the meantime the infested shoots from the field were picked over by a gang of temporary workers from the village of Farnham Royal. None of these workers had, of course, any previous training or experience in work of this kind, but they rapidly acquired sufficient knowledge to deal satisfactorily with the material. All of the infested shoots were opened and the larvæ and chrysalids of the Pine Shoot Moth, and the cocoons of the parasite, were removed, after which the shoots were sterilised in order to destroy any other insects which they might contain. Finally, after they had been carefully dried, the shoots were packed with larvæ in boxes specially constructed for the purpose. After a few experiments it was found that the larvæ could be as successfully packed between layers of tissue paper as among sterilised pine shoots, and this method was employed during the later part of the work. As the investigations progressed it was found that the larvæ parasitised by the two most important species present, developed a good deal more slowly than the others, so that by the time the work was completed and all the chrysalids removed, approximately 90 per cent. of the living larvæ remaining for shipment were parasitised. The vast majority of the parasites present belonged to two species : the one was an Ichneumonid (*Cremastus interruptor*, Grav.) and the other a Braconid (*Orgilus obscurator*, Nees.). Two shipments, comprising in all from 25,000–30,000 larvæ of the Pine Shoot Moth were despatched to Canada in cold storage. They arrived in very fair condition and although the mortality among the larvæ was very heavy owing to injuries received during the preparation of the material, about 600 specimens of the two species of parasites were reared and liberated in the infested districts.

In the following summer collections from these areas showed that these parasites had become established, and had been able to pass the severe Canadian winter successfully.

The complete list of the primary and secondary parasites reared from the Pine Tortrix during the course of this work is as follows :—

Ichneumonidæ	..	*Cremastus interruptor*, Grav.
		Eulimneria rufifemur, Thoms.
		Gelis fallax, Forst. ?
		Hemiteles bicolorinus, Grav. ?
		H. palpator, Grav. ?
		H. spp.
		Hypsantyx impressus, Grav. ?
		Lissonota transversa, Bridg.
		Omorgus borealis, Zett.
		O. ensator, Grav.
		O. mutabilis, Holmg.
		Phaeogenes spp.
		Pimpla brevicornis, Grav.
		P. detrita, Holmg. ?
		P. examinator, F.
		P. pomorum, Ratz.
		P. robusta, Morl.
		P. ruficollis, Grav.
Braconidæ	..	*Apanteles falcatus*, Nees.
		Microbracon abscissor, Nees.
		Orgilus obscurator, Nees.
		Eubadizon extensor, L.
Chalcididæ	..	*Habrocytus acutigena*, Thoms.
		Eutelus sp.
		Trichogramma evanescens, West.

A great many of these parasites had never before been recorded from the Pine Shoot Moth in England. A paper embodying some of the information obtained concerning their biology is being prepared by Dr. W. H. Thorpe.

Wood Wasps (*Sirex* spp.).

The Wood Wasps or Horntails are large wasp-like insects allied to the sawflies, whose larvæ bore into the wood of trees. Most of the forest entomologists who have studied the habits of these insects in

Europe and America are of the opinion that they do not ordinarily attack healthy trees, and must be considered to be rather indicators of pathological conditions than the cause of them. They not only attack standing trees but also felled timber, in which they sometimes do a good deal of damage. However, Chrystal ('28), who has devoted considerable attention to the problem of the wood wasps, is of the opinion that in many cases the logs attacked by *Sirex* have previously been weakened by fungus, and thus rendered worthless quite apart from the work of the insects. On the other hand, according to Tillyard ('27) and Miller ('25), the Wood Wasps are a much more serious pest in New Zealand. The chief host tree in New Zealand is *Pinus radiata*, of which the Wood Wasp not only attacks felled logs, but also living trees. The pest was originally discovered on the west coast of the North Island, but in the year 1925, it became evident that its range had considerably extended.

Owing to the anxiety caused by the work of this insect and its increase in numbers, the New Zealand Government approached the Imperial Bureau of Entomology with a request for the investigation of its parasites, with the hope that they might be introduced into New Zealand. The investigations were carried out in co-operation by Dr. R. N. Chrystal, of the Forestry Institute of Oxford, and Dr. J. G. Myers, of Farnham House Laboratory, with the assistance of Mr. H. S. Hanson. The habits of the Wood Wasps, their slow development, and the very extensive manual labour necessary in order to obtain material for study made this investigation and the task of obtaining parasite material for shipment, unusually arduous. However, in spite of these difficulties, Messrs. Myers and Chrystal succeeded in elucidating completely the life history of the *Sirex* and its inter-relations with its parasitic enemies. The results of these investigations have already been published by these authors and further papers upon the same subject by Dr. Chrystal and Mr. Hanson are now in press. Two important parasites, *Rhyssa persuasoria* and *Ibalia leucospoides* were discovered. After careful consideration it was decided for the moment to restrict the exportation to the former species.

The task of obtaining a sufficient number of the parasites of a wood-boring insect like the Wood Wasps was, of course, a problem of unusual difficulty. In order to solve it a very ingenious method was devised by Mr. Hanson. During the early summer, Mr. Hanson collected in the area in which he was working a large number of trees

infested by the Wood Wasp. These trees were felled and the logs placed in piles, arranged as shown in the accompanying photograph (Plate VIII, 2) at a considerable number of points, fairly widely separated from each other. In all, thirty of these piles of infested logs were prepared. The object of this arrangement was to secure the congregation of the parasites in large numbers. It had previously been observed by entomologists that many types of insects are attracted in large numbers to points where dense populations of their host occur, and it was hoped that by gathering together in certain isolated spots large numbers of the logs infested by the *Sirex*, a more satisfactory parasitisation would be obtained than from isolated logs or trees scattered through the whole area. Although no comparative studies were made in order to determine the efficiency of the method, the results obtained from it were remarkably satisfactory. At the close of the season, the logs were cut up and opened by Mr. Hanson, who obtained over 1,300 larvæ of *Rhyssa persuasoria*, which were shipped to New Zealand during the winter of 1928–29. The rearing of larvæ which have spent their lives in tunnels within the wood of trees or the tissues of plants often present considerable difficulties. This problem was satisfactorily solved by Dr. Myers. The larvæ of the *Rhyssa*, as collected, were placed in gelatin capsules filled with sawdust, and this method gave very good results, being much superior to that obtained by the use of glass tubes. A large number of the specimens shipped to New Zealand issued in good condition, and were liberated by Dr. Miller in infested areas where they have been observed attacking larvæ of the *Sirex* within their burrows. It is hoped that they are already established, but in any case arrangements have been made for securing a further supply of the insect next season.

The Larch Case Bearer (*Coleophora laricella*, Hubn.).

The Larch Case Bearer is so-called because the caterpillar of this insect constructs for itself out of portions of the injured leaves of the larch a case lined with silk in which it lives, feeds, and in which it passes the winter. The Larch Case Bearer sometimes causes rather severe damage by feeding upon the leaves of the Larch, the effects of its work being, in appearance, very similar to that of frost or singeing by fire. It has been accidentally introduced into Canada and is one of the problems which we have been asked to take up by the Dominion Entomologist. Work on this insect was begun by Dr. G. Salt in the summer of 1929, but at the time it was not found

possible to collect a sufficient amount of material. Later in the same year, Mr. H. S. Hanson was detailed to the work of collection, and during the course of the autumn and winter he visited a considerable number of localities and succeeded in collecting in Cambridgeshire and Shropshire a number of large sacks of larch twigs, bearing the hibernating caterpillars of the pest. Specimens of these caterpillars were dissected from each of the various areas and at least three species of parasites were discovered. The study of these parasites is now being continued by Dr. Thorpe. One of them seems to be of considerable importance as a controlling agent of the Case Bearer and it will not be difficult to obtain a quantity sufficient for shipment.

In addition to these forest pests investigations, investigations have been begun on the Beech Coccus (*Cryptococcus fagi*, Baren) ; and the Larch Sawfly (*Lygaeonematus erichsoni*, Htg.), but have not as yet yielded any definite results. We have also been requested to find parasites or predators of the Pine Chermes (*Chermes pini*, L.), the Hemlock Looper (*Ellopia fiscellaria*, Gn.), the Pine Bud-moth (*Exotelia dodecella*, Linn.), the Willow Sawfly (*Nematus pallidiventris*), the Spruce Aphis (*Myzaphis abietina*, Wlk.), the Satin Moth (*Stilpnotia salicis*, Linn.), and the Spruce Bud-worm (*Tortrix fumiferana*, Clem.).

3. *Parasites of Insects of Cereal and Forage Crops.*

The Lucerne Springtail (*Symnthurus viridis*, L.).

The Lucerne Springtail belongs to one of the lowest orders of insects, which is very widely distributed throughout Europe, and has become accidentally introduced into Australia. In Europe the damage it causes though certainly not negligible in certain cases and at certain times, has probably been attributed to other species, and consequently has attracted very little attention. In Australia and more particularly in Western Australia, in certain regions where Lucerne is very extensively grown, this insect has proved to be a very injurious pest. It is especially destructive to young plants.

An investigation of the natural enemies of this species was begun in 1927. No parasites were discovered, but several predacious insects which feed upon the Springtails were found by Dr. J. G. Myers. However, it soon became evident that without a general investigation it was impossible to come to any conclusion as to the importance of these predators as controlling factors of the Springtail. It was therefore decided to investigate the natural control of

Symnthurus viridis as completely as possible. This work was assigned to Mr. D. Stewart MacLagan, a scholar of the Ministry of Agriculture for Scotland, who has continued it without interruption from the autumn of 1928, until the present time. The list of predators of various kinds has been considerably extended and a great deal of valuable information has been obtained pertaining to their relative value under laboratory conditions. If investigations in Australia show that some of the more important of these predators are absent, steps will be taken to introduce them into the infested areas. However, it is not considered advisable to attempt this at present, as the work of breeding and shipping these predators is likely to be extremely difficult and laborious. Furthermore, the investigations carried on by Mr. MacLagan show conclusively that while these predators undoubtedly play some small part in the natural control of *Smynthurus viridis*, the fluctuations in numbers of this insect are primarily dependent upon the meteorological factors. The work carried on by Mr. MacLagan in connection with this species constitutes a very valuable contribution to the problem of natural control, and it is hoped that it will soon be published.

The Wheat Stem Sawfly (*Cephus cinctus*, Nort.).

The Wheat Stem Sawfly is an insect native to North America, which has gradually spread from wild grasses to cultivated grain crops, and will probably become more and more injurious as time goes on. Its larva bores in the stem of the wheat plant and before it forms its cocoon it partly cuts through the wall of the wheat stem, just above the place where it intends to pupate. This weakens the stem so that it breaks off very easily, and of these fallen stalks a great many are, of course, destroyed or lost during the work of harvesting. This insect is considered by the Canadian entomologists to be the most serious pest of wheat in the Western Provinces. Heavy infestations have occurred repeatedly. In 1922 serious damage was caused, 12,000 acres being affected in Manitoba in that year ; in 1926, the loss in Saskatchewan alone was estimated to be in the neighbourhood of 12,000,000 dollars. Parasitic insects, native to Canada, are said to keep the pest under control in the wild grasses, but they have proved to be quite ineffective in the grain fields ; one reason apparently being that their ovipositors are too short to reach the larva of the Sawfly in the Wheat stem. As has already been stated the Wheat Stem Sawfly is a native of Canada and does

not exist in Europe. It is, however, replaced here by a European Sawfly (*Cephus pygmaeus*, L.), which is very similar in structure and habits. A study of this insect and its parasites was therefore undertaken in the hope that they might be of use in controlling the Wheat Stem Sawfly.

During the course of the investigations, which have been in charge of Dr. G. Salt, examples of wheat stubble have been examined from a total of about 70 fields in several parts of the country. In no case was the Sawfly found to be abundant. In fields at Rothamsted, which have been under wheat for a very long period, the most heavily infested fields had only from ten to twelve per cent. of the stems affected, though 60 to 70 per cent. infestation is not uncommon in north America. The reason for the apparent scarcity of the insect seems to be that it is very heavily attacked by several parasites. During the course of the investigations, Dr. Salt and his assistants have examined a total of approximately 34,000 stems. Five principal parasites have been discovered, which destroy, taken together, from 70 to 100 per cent. of the larvæ of the Sawfly. Of these parasites one is particularly important and accounts alone, on the average, for about 60 per cent of the Sawfly larvæ. It has not, of course, been proved that this species will attack the Canadian Wheat Stem Sawfly, but there is every reason to suppose that it will, because it is commonly found as a parasite of another sawfly attacking wheat (*Trachelus tabidus*) which is much less closely related to the Canadian species than is the European Wheat Stem Sawfly. Another point of interest concerning this parasite is that it is commonly found attacking the Wheat Stem Sawfly in Russia, where, as is well known, the climatic and other conditions are very similar to those of the great wheat-growing areas of the Canadian West. Dr. Salt is at present carrying on a very careful investigation of the biology and the inter-relations of the parasites of the Wheat Stem Sawfly, and has shipped to Canada approximately 9,000 specimens of the most common species, which arrived in excellent condition. However, in view of the vast extent of the infected area and the magnitude of this problem, it is obvious that in order to obtain relief from the attack of this insect within reasonable time, the work on the collection and shipment of parasites must be organised on a very much larger scale. So far as we know the principal parasite of the Sawfly has only a single generation a year, so that it is not possible to rely upon artificial breeding methods for obtaining it in large numbers. In this case the collection over large areas is the only practicable method that can be applied.

The list of parasites obtained from the Wheat Stem Sawfly is as follows :—

Collyria calcitrator, Grav.
Pimpla detrita, Holgr.
Hemiteles hemipterus, Fabr.
Hemiteles, sp.
Microbracon terebella, Wesm., var. *Wesmaeli*, Fabr.
Pleurotropis benefica, Gahan.
Eurytoma appendigaster, Boh.
Homoporus, sp.

Of these, *Collyria calcitrator*, *Pimpla detrita*, *Microbracon terebella* and *Pleurotropis benefica* are apparently primaries; the status of the remainder is, as yet, uncertain.

In addition to these pests we have been asked to obtain the natural enemies of an Australian White Grub (*Anodontonyx tetricus*), the Red Mite (*Bryobia praetiosa*, Koch.), the Corn Ear Worm (*Heliothis obsoleta*, Fabr.), the Clover Weevil (*Listroderes praemorsa*), the New Zealand Cockchafer (*Odontria Zealandica*, White), the Grass Moths (*Porina* spp.), and the European Corn Borer (*Pyrausta nubilalis*, Hubn.).

4. *Parasites of Insects of Vegetable and Garden Crops.*

The European Earwig (*Forficula auricularia*, L.).

The common Earwig is an insect generally distributed throughout Europe, North Africa, and Western Asia, which has been accidentally introduced into Tasmania, Australia, East Africa, the East Indies, North America, and New Zealand. It is a polyphagous insect, feeding on both animal and vegetable matter, but is sometimes distinctly injurious to vegetation. In North America, where it now occurs in the States of California, Oregon, and Washington and in the Province of British Columbia in the West, and in the State of Rhode Island in the East, and in New Zealand, it is regarded as a rather serious pest owing to its habits of entering houses and the fact that it feeds on fruit and flowers. The earwig is attacked in

Europe by two Dipterous parasites, *Digonochaeta setipennis*, Fall., and *Rhacodineura antiqua*, Meig. (Thompson, 1928) of which the former is by far the more important.

A number of years ago, with the co-operation of Dr. A. D. Imms, Dr. Tillyard attempted to introduce the parasites of the Earwig into New Zealand, but as far as can be ascertained, these introductions were unsuccessful, though, at least one of the parasites was bred through two generations in captivity. It was, therefore, decided to make further attempts to introduce it, especially since material was also requested by the Dominion Entomologist for distribution in Western Canada.

Both of the parasites of the earwig can be bred in captivity, but in view of the labour entailed by this method, we have not adopted it, but have obtained our material of the parasite from a professional collector, Mr. B. S. Harwood of Sudbury, who, after having been given specimens and instructions can practically always be relied upon to collect a sufficient number of puparia in the field. In order to avoid any risks from such hyperparasites as may be present, the puparia are isolated in gelatin capsules in which they are shipped during the period of hibernation.

From March, 1928, to the present date, four shipments, with a total of 1,185 puparia of *Digonochaeta* have been sent to New Zealand, and six shipments with a total of 1,218 puparia to Canada. All of these shipments arrived in good condition, and produced healthy flies which were liberated in the infested areas.

The Diamond Back Moth (*Plutella maculipennis*, Curt.).

This insect is a native of Europe, but now exists also in Greenland, Spitzbergen, North America, the Argentine, Cuba, South and East Africa, India, Australia, New Zealand and Hawaii. It attacks principally Cruciferous plants, such as cabbage, swedes, kale, turnip, etc., on which it sometimes causes very serious damage. The larvæ first mine within the leaves, but later feed externally.

Both the Governments of Canada and New Zealand have requested us to supply parasites of this pest, which has, in Europe, a number of natural enemies. Preliminary investigations in North-Western France were made by Mr. Kozlovsky during the course of 1928. One parasite, *Angitia plutellæ*, Vier., was obtained in fair numbers, and successfully bred by Mr. Kozlovsky in the laboratory; but no shipments have yet been made.

Woodlice (*Porcellio* and *Oniscus*, spp.).

These creatures, which are widely distributed throughout the world and occasionally assume the status of a pest, should, strictly speaking, be placed in a separate section, since they are not insects but Crustacea, belonging to the group of the Isopoda.

In New Zealand, they sometimes do a good deal of damage, both in greenhouses and in the open, and were included in a list of projects submitted to the Laboratory by the entomologist of the Cawthron Institute.

A general study of the parasites of Woodlice, begun a number of years ago by the Superintendent, is now being continued. The insect parasites found infecting Woodlice are all Diptera and are as follows :—

Plesina maculata, Fall.
Stevenia umbratica, Fall.
Ptilocerina atramentaria, Meig.
Styloneuria discrepans, Pand.
Frauenfeldia rubricosa, Meig.
Melanophora roralis, L.
Phyto melanocephala, Meig.
Rhinophora lepida, Meig.
Cyrillia angustifrons, Rond.

All of these appear to be closely related forms. Two shipments, comprising about 14,019 Woodlice, collected for the most part in North-Eastern France by Mr. Kozlovsky and known to contain several of the parasites mentioned, were shipped to New Zealand in May, 1929.

The Carrot Rust Fly (*Psila rosae*, L.).

The Carrot Rust Fly is a native of Europe, but has been known in Canada from as early as the year 1885. In the years following its introduction it spread southward, and is now distributed through the Northern United States from Maine to Michigan. It attacks the roots of celery and burrows into carrots and parsnips, continuing its work in stored carrots, even during the winter.

Requests for the parasites of this insect have been received from both the Dominion Entomologist in Canada and from the Entomologist of the New York Experiment Station. Three species

of Hymenopterous parasites, two of the genus Dacnusa and another known as *Aphaereta cephalotes*, Hal., were bred a few years ago from the puparia by Smith and Gardner.

Preliminary collections, which now comprise about 2,000 larvæ and pupæ, have been made by Mr. Hanson in the Midlands, and as soon as the biology of the parasites is satisfactorily known, shipments of the most promising species will be made.

The Potato Tuber Moth (*Phthorimaea operculella*, Zell.).

This insect is a cosmopolitan pest, whose origin is at present not certainly known. It is particularly injurious to Potato, attacking not only the leaves and stems, but also the tubers, especially those which have been placed in storage. Some years ago it appeared in Southern France, and is now present in Cyprus.

In response to a request for parasites of the insect from the Entomologist of Cyprus, the United States Bureau of Entomology was asked to supply us with a consignment of *Microbracon Johanseni*, Vier., which is an important enemy of the pest in California. The attempts to secure this parasite in 1929 were unsuccessful, owing to the unfavourable season, but it is hoped that it will be sent to us during the present summer.

In addition to the above insects we have been asked to investigate the parasites of the Potato Stem Borer (*Gortyna micacea*, sp.), the Onion Maggot (*Hylemyia antiqua*, Meig.), the Onion Thrips (*Thrips tabaci*, Lind.), and the Current Sawfly (*Pteronus ribesi*, Scop.).

5. *Parasites of Tropical Field Crop Insects.*

The Pink Boll-worm (*Platyedra gossypiella*, Saund.).

This insect is a very important pest of cotton, which was first described from India, though its native home is uncertain. It now exists in many parts of the world, including the Sudan, the United States, where it was first discovered in 1917, and the West Indies, where it appeared in 1920.

In response to a request from the Entomologist of Barbados, a consignment of cocoons of *Microbracon kirkpatricki*, Wilk., an important parasite of the Pink Boll-worm, which attacks it in the Sudan, was obtained in 1929 from Mr. H. H. King, Chief Entomologist

of the Sudan, and sent on at once, with the help of the West India Committee, to Barbados. The material arrived in very fair condition, but owing to unavoidable accidents it was not found possible to breed it. Further consignments in a somewhat more favourable condition have now been received from the Sudan. One consignment has been sent to the West Indies, and two others, from material bred in the Laboratory by Dr. Thorpe, have been despatched to the United States Bureau of Entomology, whence a further request for this parasite was received.

The most important work on Tropical Crops is, of course, that being carried out by Dr. J. G. Myers.

6. *Parasites of Citrus Fruit Insects.*

The Fluted Scale (*Icerya purchasi*, Mask.).

The Fluted Scale is an insect of Australian origin, which, in the absence of its natural enemies, has been in many parts of the world a most devastating pest of citrus fruits. The use of the Vedalia Ladybird (*Rodolia cardinalis*, Muls.) against this scale constitutes one of the most remarkable examples of successful biological control. In practically all parts of the world where the ladybird has been introduced the infestations have been practically annihilated in an extraordinarily short time.

Some years ago the Fluted Scale began to be troublesome in certain districts of the Madras Presidency and after unsuccessful attempts to secure the Vedalia Ladybird elsewhere, the Entomologist of the Presidency, Mr. Y. Ramachandra Rao, applied to the Imperial Bureau of Entomology for a consignment. This was secured early in 1929 from California, through the kind assistance of Professor H. S. Smith, and at once despatched to Colombo. Here it was met by an assistant from the entomological department of the Madras Presidency and taken at once to Coimbatore. Breeding work was at once begun and according to the last report received (July 31st, 1929) the stock had been increased to 380 adult beetles, 350 pupæ, 5,000 larvæ and 5,000 eggs. Preparations for the distribution of the material in the infested areas were then being made.

Other insects of Citrus Fruits, whose parasites have been requested are the White Wax Scale (*Ceroplastes ceriferus*, And.), the Pink Wax

Scale (*Ceroplastes rubens*, Mask.), the Orange Snow Scale (*Chionaspis citri*, Comst.) and the Mediterranean Fruit Fly (*Ceratitis capitata*, Wied.).

7. *Parasites of Greenhouse Insects.*

The White Fly (*Trialeurodes vaporariorum*, Westw.).

This well-known pest of greenhouse plants is generally distributed throughout Europe and America, and the same or similar species exist in other parts of the world, such as New Zealand. Until recent years it has been necessary to fight the White Fly by fumigation, which is sometimes injurious to the plants. Now, however, owing to the careful and painstaking work of E. Speyer, Entomologist of the Research Station of Cheshunt, it has been found possible to utilise an imported Chalcid parasite (*Encarsia formosa*, Gahan) very effectively against the pest. By the employment of ingenious special methods Mr. Speyer has succeeded in breeding the parasite artificially in very large numbers for distribution throughout the greenhouses of this country. A combination of a relatively small colony of these parasites, with a light fumigation has proved an excellent practical remedy for the White Fly.

By special arrangement material of this parasite is available for distribution by Farnham Royal to any part of the Empire where it may be required. A shipment comprising from 15,000 to 20,000 specimens of *Encarsia formosa* was sent to Canada in 1928, at the request of the Dominion Entomologist and the parasites liberated in infested greenhouses. It was then found that the species was already present in the district, but the introduction has served good purpose in calling the attention of the entomologists of the Dominion to the useful rôle of the parasite.

8. *Parasites of Insects affecting Man and Domestic Animals.*

The Sheep Blowflies (*Lucilia sericata*, Meig., etc.).

This group of pests includes a number of species commonly known as Greenbottles or Bluebottles, which in the earlier stages usually live in decomposing animal matter, but sometimes attack living animals producing what is technically known as myiasis. In countries where flocks are small and carefully tended the trouble is not serious, but fairly heavy losses occur in the vast sheep farms in many parts of

America, Australasia and South Africa. In Queensland, approximately 5 per cent. of the sheep are lost through the Blowflies, in New Zealand the losses are estimated at about 1 per cent. in spite of careful attention, while in South Africa it is believed that the annual loss from this cause is over £78,000 (Smits, '29).

The relative importance of the various species of flies associated with myiasis in sheep is not at present well understood. It seems, however, that one of the most important forms is the common Greenbottle, *Lucilia sericata*, Meig., an insect of European origin, which is now distributed all over the world. The parasites and predators of this species have, therefore, received special attention from all those interested in this problem.

A careful study of the biology of *Alysia manducator*, Panz., the principal parasite of *Lucilia sericata* was published in 1920 by Altson, but in view of the demand for this parasite and the growing importance of the problem, the Director of the Imperial Bureau of Entomology decided to reopen the investigation, which was assigned to Dr. J. G. Myers early in 1927. As a result of this work, three shipments of parasitised puparia of *Lucilia*, containing over 1,800 specimens were sent to the entomologists of New South Wales, Western Australia and New Zealand, in the autumn of the same year. In the early part of 1928, another lot of 100 puparia was sent to the Entomologist of New South Wales, and another comprising 1,220 puparia and 2,690 larvæ was despatched to him in October of the same year. In November, 1928, a consignment of 800 parasitised puparia was shipped to South Africa. All of these consignments arrived in a satisfactory condition, and provided a large number of adults of the parasite, which were either liberated in the infested areas or used for breeding work. It is satisfactory to be able to report that Dr. D. Miller of the Cawthron Institute has now recovered *Alysia manducator* from the field so that it has evidently established itself in New Zealand.

The development of the breeding methods used in the work is of considerable interest. During the work carried on in 1928, the Blowflies were reared on dead cats, which were obtained, freshly killed, from London and sent to the Laboratory in sealed sacks. These cats were placed in large shallow enamelled pans in a special insectary, situated at some distance from the main buildings of the Laboratory, and identified females of *Lucilia sericata* liberated in it. Within a short time the carcases of the cats were swarming with the maggots

of the Blowflies. Attracted by the odour of the decomposition, various carrion-feeding insects, together with their parasites and predators began to congregate in the vicinity of the insectary. Among these were numerous specimens of *Alysia manducator*, which were collected and introduced into the compartment with the Blowflies, where they at once began to search for maggots in the decomposing carcases. As the maggots of the Blowflies completed their larval development they left the trays and fell to the floor, where they assembled between large sheets of brown paper placed there for the purpose. In order to avoid hyperparasitism by the Chalcid *Nasonia brevicornis*, which attacks the puparia of the Blowfly, the maggots were removed before pupation and stored in sand in large glass jars, which were closed with heavy cloth covers and buried to the neck in earth in another insectary, situated some distance away.

In this way a supply of some 200,000 maggots of *Lucilia sericata*, of which many were parasitised by *Alysia manducator*, was easily obtained.

However, after further very careful investigations it was found by Dr. Salt that a supply of freshly killed animals was unnecessary, and that oviposition could be obtained and larvæ reared with much greater economy in space, material and time, on minced butchers' meat. Finally, instead of allowing the parasite to search for the larvæ of the Blowfly in the carrion it has been found much better to place larvæ of a suitable size in small glass containers with *Alysia* females ready to oviposit, removing the maggots one by one as fast as they are stung by the parasite. Furthermore, all the specimens obtained by this method are known to contain larvæ of *Alysia*, so that there is no loss through the storage and shipment of unparasitised material.

Up to the present date, seven shipments, comprising a total of 6,600 puparia, parasitised by *Alysia manducator* have been sent from the Laboratory, four to Australia, one to New Zealand and one to South Africa. A reserve stock of the parasite is kept permanently on hand in case further shipments are required. Stocks of other important parasites and predators of Blowflies will be bred up as the occasion arises.

Bluebottle (*Calliphora* spp.).

The Braconid parasite (*Alysia manducator*, Panz.) of the Sheep Blowfly not infrequently attacks other carrion-feeding flies of the same group, and is often reared from the Bluebottle (*Calliphora*

spp.). These latter insects are a great nuisance in the Falkland Islands, owing to their habit of entering houses. With the hope of reducing their numbers a shipment of parasitised puparia was requested by the authorities of the Islands. This was sent out in the autumn of 1927, and parasites from the same stock are still being bred.

The Horn Fly or Buffalo Fly (*Lyperosia irritans*, L.).

This insect and certain closely allied forms are serious pests of cattle in many parts of the world (North America, New Zealand, Australia). The larvæ live in freshly deposited manure, but the adults are blood-sucking congregating in masses around the bases of the horns of the host animals.

Parasites of this insect have been requested by the Governments of both Canada and New Zealand, and investigations are now under way on this project in North-Eastern France, where Mr. Kozlovsky has found the Horn Fly in fair numbers in certain districts (Caen and St. Pierre-sur-Dives (Calvados)).

Other pests affecting domestic animals, we have been asked to investigate, are the New Zealand Cattle Tick (*Haemaphysalis bispinosa*, Neum.) and the Warble Flies (*Hypoderma bovis*, Degeer and *lineatum*, Vill.).

In all, fifty-seven consignments of the parasites and predators of insect pests, comprising a total of 115,000 individuals, have been sent out from the Laboratory; at least 21 species of beneficial insects attacking pests belonging to 14 species have been included in these shipments.

9. *Investigations in the West Indies.*

In October, 1928, Dr. J. G. Myers left for the West Indies, in order to investigate the possibilities of the method of biological control in the Islands, with special reference to the pests of Sugar Cane.

As it was obviously undesirable to attempt the introduction of beneficial parasites from one West Indian island to another until precise information was available as to the actual position of each of the Colonies, Dr. Myers' work during the past year has had to be almost entirely of an exploratory nature. He has visited Trinidad, British Guiana, Surinam, Barbados, Cuba, Jamaica, and Haiti, and

many thousands of insect pests have been dissected or reared in captivity in order to ascertain what parasites were already present in each country, and the percentage of parasitism. A large body of useful preliminary information has thus been accumulated.

The position with regard to the Hymenopterous parasites of the small moth borers of sugar-cane (*Diatraea*) in Trinidad and British Guiana was found to be so complex and puzzling, that it will be necessary to investigate the matter much more fully before the introduction of parasites is undertaken, and it is probable that arrangements will be made locally for the appointment of a special entomologist to study the problem in each country. An apparently valuable parasite of these insects occurs in Cuba, a Tachinid fly (*Lixophaga*), and arrangements have been made with the Harvard Biological Laboratory in that island to collect a supply of this insect for introduction this spring into Barbados, in the first instance.

Attempts to obtain parasites of the large cane borer (*Castnia*), the cacao beetle (*Stirastoma*), and the sweet potato weevil (*Euscepes*), on the mainland of South America unfortunately failed on account of the extreme rarity of these insects on their natural food-plants, and time was not available for any extensive search. But this very rarity indicates that important controlling factors are in operation, and these should be worth examining when an opportunity is available.

The freedom of sugar-cane from froghoppers in Cuba was found not to be due to any control by parasites. Possibly an important factor is the occurrence of lime in the soil in large quantities.

10. *Noxious Weed Work.*

The devastating effects often exerted by Phytophagous insects upon vegetation constitutes the most important problem in economic entomology. However, these insects attack noxious as well as useful plants, and must therefore, in many cases, be considered as beneficial organisms. The idea of utilising them for the destruction of weeds and other harmful plants is relatively new and seems to have originated with Perkins and Koebele in relation to Lantana in Hawaii. It was adopted a number of years later by the Australian authorities against Prickly Pear, and extended to other noxious plants in New Zealand and Australia by Tillyard.

The most injurious weeds of European origin in New Zealand are the Blackberry (*Rubus fruticosus*), the Gorse (*Ulex europaeus*) and the Ragwort (*Senecio jacobaea*), while Foxglove (*Digitalis purpurea*) and Bracken (*Pteris aquilinia*) are also rather troublesome.

The work on the European insects attacking these plants was carried on in the first instance at Rothamsted and Leeds, but centralised in 1929 at Farnham Royal. In view of the fact that the problem of weed control by insects is in a very large measure a botanical problem, it was decided to organise it upon new lines, and to combine with the entomological work previously carried on, a careful ecological study of the natural control of the weeds mentioned in their native haunts, and a detailed investigation of the effect produced by their insect enemies in limiting their growth, distribution and increase. During the season of 1929 this work was in the charge of Dr. A. S. Watt, formerly Lecturer in Forest Botany and Zoology in the University of Aberdeen. On October 1st, 1929, Dr. Watt resigned to take up the post of Lecturer in Forest Botany at the University of Cambridge, and was replaced by Mr. E. H. Chater, formerly Lecturer in Ecology in the University of Aberdeen, who took up his duties on November 1st. Mr. E. Cameron, a graduate of the University of Edinburgh was given a temporary appointment as from September 27th, 1929, to assist Mr. Chater.

In spite of the delays and interruptions the work has proceeded in a very satisfactory manner. A great deal of valuable information concerning the natural control of Gorse and Ragwort, and the work of their insect enemies has been gained.

The collection and shipment of several of the most important insects attacking Gorse, Blackberry, and Ragwort has been carried on as rapidly as possible. Seven shipments, comprising a total of 90,000 individuals of *Apion ulicis*, a weevil attacking the seeds of Gorse, five shipments comprising a total of 78,028 individuals of *Tyria jacobaeae*, a moth, whose caterpillar is very destructive to Ragwort and four shipments, comprising 1,317 rose stocks infested with *Coraebus rubi*, a Buprestid beetle injurious to Blackberry, as well as 768 eggs and adults of this species, had been made up to the end of February, 1930. This material seems to have arrived, for the most part, in excellent condition, and is being used either for experimental studies or for distribution in the field.

In addition to the work of preparing and sending off shipments of parasites to New Zealand, a general study is being made of the

conditions of growth of *Ulex europaeus* and *Senecio jacobaea*. Work of this nature is determined by seasonal opportunities and up to the present the study of *Ulex* has mainly centred on two aspects of the problem, firstly, the conditions of germination of the seed, which process is markedly irregular on account of the impermeable nature of many of the seed coats, and secondly, the observation and measurement on marked plots at regular intervals of the appearance, establishment, and growth of seedlings, their colonisation of burnt ground and their competition with different plant communities.

In addition, laboratory experiments are being carried out to investigate the following points :—Root development in different types of soil ; growth in acid and calcareous soils ; infestation of seedlings by nitrogen fixing bacteria.

In the summer of 1929, the effect of phytophagous insects on *Ulex* was studied by Dr. Watt ; this aspect will again be emphasised especially with regard to seed mortality as soon as the fruiting period commences.

Ragwort investigations are being carried out along several lines, entomological, botanical, and partly agricultural. Various facts regarding the effectiveness of the Cinnabar Moth, *Tyria jacobaeae* as a means of control are being brought to light, and a fairly complete study of its parasites, both insect and fungi with a view to determining its mortality throughout the year is being made. Lists of other insects, which may prove useful, are being made, and the study of the damage or control effected by each will be carried out during the coming season. Several puparia of a fly, *Phorbia seneciella*, which appears to be helpful in certain parts of the country have been obtained.

From the botanical aspect, conditions of germination, relation to soils, temperature and relative humidity, are being looked into, and a more or less complete ecological study will be made of the plant, although this will take second place to the entomological investigations.

As an agricultural weed in England, a survey is being made of its occurrence throughout the southern part of the country, and its relation to land types, together with the competition it suffers from various grasses and agricultural plants. Notes will also be made on its poisonous properties and the behaviour of farm and wild animals towards it.

In all 16 consignments of three species of phytophagous insects, attacking three weeds of major importance in New Zealand, and comprising in all a total of 170,113 individual insects have now been sent out from the Laboratory.

11. *General Investigations.*

In addition to the essentially practical work described in the last section, a number of lines of research on fundamental problems are being carried on. The Superintendent is continuing a series of theoretical studies on the problems of natural control, considered mainly from the quantitative standpoint, as well as certain special studies on the biology of parasites and their inter-relations with their hosts. Dr. G. Salt is making a careful analytic study of the inter-relations between the Sheep Blowfly and its parasite, *Alysia manducator*, Panz., more particularly from the numerical standpoint, and has also in preparation a comprehensive paper on the biology and larval forms of the parasites of the Wheat Stem Sawfly. Dr. W. H. Thorpe is making plans for an investigation of the interaction between predacious insects and their hosts. Mr. H. T. Rosenberg is engaged in the preparation of monographs of the parasites of the Pear Slug and the Codling Moth. Mr. D. S. MacLagan has practically completed a very valuable study of the bionomics and natural control of the Lucerne Springtail. Finally Mr. E. H. Chater and Mr. E. Cameron are devoting special attention to the part played by phytophagous insects in the natural control of vegetation. Fifteen articles on various aspects of the work have been published by Dr. J. G. Myers, Dr. G. Salt, and the Superintendent.

12. *Summary of the Projects submitted to the Laboratory.*

Noxious Insects.

CANADA.

Peach Twig Borer (*Anarsia lineatella*, Zell.).
ø Pear Slug (*Caliroa limacina*, Retz.).
Wheat Stem Sawfly (*Cephus cinctus*, Nort.).
Larch Case Bearer (*Coleophora laricella*, Hubn.).
Beech Coccus (*Cryptococcus fagi*, Baren).

ø The sign ø indicates that the project is being investigated for more than one of the Governments shown above.

Oriental Peach Moth (*Cydia molesta*, Busck.).
ø Codling Moth (*Cydia pomonella*, L.).
Hemlock Looper (*Ellopia fiscellaria*, Gn.).
Apple Bud Moth (*Eucosma ocellana*, Schiff.).
Pine Bud Moth (*Exotelia dodecella*, L.).
ø European Earwig (*Forficula auricularia*, L.).
Potato Stem Borer (*Gortyna micacea*, Esp.).
Warble Flies (*Hypoderma bovis*, De Geer and *Hypoderma lineatum*, Vill.).
Hawthorn Scale (*Lecanium coryli*, Ldgr.).
Larch Sawfly (*Lygaeonematus erichsoni*, Htg.).
Horn Fly (*Lyperosia irritans*, L.).
Willow Sawfly (*Nematus pallidiventris*).
Onion Maggot (*Hylemyia antiqua*, Meig.).
ø Diamond Back Moth (*Plutella maculipennis*, Curt.).
ø Carrot Rust Fly (*Psila rosae*, Fabr.).
Apple Sucker (*Psylla mali*, Schmidb.).
Currant Sawfly (*Pteronus ribesii*, Scop.).
European Corn Borer (*Pyrausta nubilalis*, Hubn.).
Pine Shoot Moth (*Rhyacionia buoliana*, Schiff.).
Satin Moth (*Stilpnota salicis*, L.).
Onion Thrips (*Thrips tabaci*, Lind.).
Spruce Budworm (*Tortrix fumiferana*, Clem.).
Greenhouse White Fly (*Trialeurodes vaporariorum*, Westw.).

AUSTRALIA.

New South Wales.

White Grubs (*Anodontonyx tetricus*).
ø Pear Slug (*Caliroa limacina*, Retz.).
Mediterranean Fruit Fly (*Ceratitis capitata*, Wied.).
White Wax Scale (*Ceroplastes ceriferus*, And.).
Pink Wax Scale (*Ceroplastes rubens*, Mask.).
Orange Wax Scale (*Chionaspis citri*, Comst.).
ø Codling Moth (*Cydia pomonella*, L.).
Queensland Fruit Fly (*Dacus ferrugineus*, Fabr.).
ø Corn Earworm (*Heliothis obsoleta*, Fabr.).
ø Sheep Blowfly (*Lucilia sericata*, Meig., etc.).

ø The sign ø indicates that the project is being investigated for more than one of the Governments shown above.

Western Australia.

Red Mite (*Bryobia praetiosa*, Koch.).
ø Pear Slug (*Caliroa limacina*, Retz.).
ø Corn Earworm (*Heliothis obsoleta*, Fabr.).
Clover Weevil (*Listroderes praemorsa*).
ø Sheep Blowflies (*Lucilia sericata*, Meig.).
Lucerne Springtail (*Smynthurus viridis*, L.).

SOUTH AFRICA.

ø Sheep Blowfly (*Lucilia sericata*, Meig.).

NEW ZEALAND.

ø Pear Slug (*Caliroa limacina*, Retz.).
Pine Chermes (*Chermes pini*, L.).
Pear Leaf-curling Midge (*Dasyneura pyri*, Bouché).
Bronze Beetle (*Eucolaspis brunnea*, Fabr.).
ø European Earwig (*Forficula auricularia*, L.).
Cattle Tick (*Haemaphysalis bispinosa*, Neum.).
ø Sheep Blowflies (*Lucilia sericata*, Meig.).
Spruce Aphis (*Neomyzaphis abietina*, Walk.).
New Zealand Cockchafer (*Odontria zealandica*, White).
ø Diamond Back Moth (*Plutella maculipennis*, Curt.).
Woodlice (*Porcellio* spp.).
Grass Moths (*Porina* spp.).
Wood Wasps (*Sirex* spp.).
Apple Leaf Hopper (*Typhlocyba australis*, Frogg.).

INDIA.

United Provinces.

Woolly Aphis (*Eriosoma lanigerum*, Hausm.).

Madras Presidency.

Fluted Scale (*Icerya purchasi*, Mask.).

WEST INDIES.

ø Pink Bollworm (*Platyedra gossypiella*, Scund.).

ø The sign ø indicates that the project is being investigated for more than one of the Governments shown above.

CYPRUS.

ø Codling Moth (*Cydia pomonella*, L.).
Potato Tuber Moth (*Phthorimaea operculella*, Zell.).

FALKLAND ISLANDS.

Bluebottles (*Calliphora* spp.).

UNITED STATES OF AMERICA.

ø Pink Bollworm (*Platyedra gossypiella*, Saund.).
ø Carrot Rust Fly (*Psila rosae*, L.).

Noxious Weeds.

NEW ZEALAND.

Gorse (*Ulex europaeus*, L.).
Blackberry (*Rubus fruticosus*, L., etc.).
Ragwort (*Senecio jacobaea*, L.).
Foxglove (*Digitalis purpurea*, L.).
Bracken (*Pteris aquilina*, L.).

Up to the date on which this manuscript was sent to the press, a total of 73 consignments of beneficial insects, containing approximately 285,000 living individuals have been sent out by the Laboratory. About twenty-four species of beneficial insects attacking seventeen species of pests have been included in these shipments. In addition, Mr. Stanley Garthside has shipped to Australia four lots of the three Chrysomelids attacking St. John's Wort, comprising 28,798 individuals in various stages of development.

ø The sign ø indicates that the project is being investigated for more than one of the Governments shown above.

V. BIBLIOGRAPHY.

Altson, A. M., 1920.

The Life History and Habits of two Parasites of Blowflies.
Proc. Zool. Soc., London, 1920, pp. 195–243, 20 figs.

——, 1924.

Parasites bred in Captivity.
Proc. Ent. Soc., London, 1924, pp. XIV–XV.

Ayers, H., 1884.

On the Development of *Oecanthus niveus* and its Parasite, *Teleas*.
Mem. Boston Soc. Nat. Hist., iii, pp. 225–281, 8 pls., 41 figs.

Baume Pluvinel, G. de la, 1914.

Evolution et formes larvaires d'un Braconide (*Adelura gahani* n. sp.) parasite interne de la larve d'un Phytomyzinae.
Arch. Zool. exp. gén., lv, pp. 47–59.

Chrystal, R. N., 1928.

The *Sirex* Wood Wasps and their Importance in Forestry.
Bull. Ent. Res., xix, pp. 219–247, 3 pls., 10 figs.

—— and Myers, J. G., 1928.

Natural Enemies of *Sirex cyaneus* Fabr., in England and their Life-histories.
Bull. Ent. Res., xix, pp. 67–77, 1 pl.

Crossman, S. S., 1922.

Apanteles melanoscelus, an imported Parasite of the Gipsy Moth.
Bull. U.S. Dept. Agric., No. 1028, 25 pp. 4 pls., 1 map, 1 fig.

——, 1925.

Two imported Egg Parasites of the Gipsy Moth, *Anastatus bifasciatus* Fonsc., and *Schedius kuvanae* Howard.
J. Agric. Res., xxx, pp. 643–675, 11 figs.

Cushman, R. A., 1926.

Some Types of Parasitism among the Ichneumonidæ.
Proc. Ent. Soc., Washington, xxviii, pp 29–51., 5 pls., 1 fig.

Davies, W. M., 1928.

The Bionomics of *Apion ulicis* Först (Gorse Weevil), with special reference to its rôle in the control of *Ulex europæus* in New Zealand.
Ann. Appl. Biol., xv, pp. 263–286, 3 pls., 3 figs.

Dodd, A. P., 1927.

The Biological Control of Prickly Pear. Investigations of the Commonwealth Prickly Pear Board.
J. Counc. Sci. Ind. Res., Melbourne, i, pp. 48–54, 4 pls.

Eastham, L. E. S., 1929.

The post-embryonic Development of *Phænoserphus viator* Hal. (Proctotrypoidea), a Parasite of the Larva of *Pterostichus niger* (Carabidæ).
Parasitology, xxi, pp. 1–21, 3 pls., 1 fig.

Fiske, W. F., 1910.
Superparasitism : An important factor in the Natural Control of Insects.
J. Econ. Ent., iii, pp. 88–97, 1 fig.

Flanders, S. E., 1929.
The Production and Distribution of *Trichogramma*.
J. Econ. Ent., xxii, pp. 245–248.

Genieys, P., 1925.
Habrobracon brevicornis, Wesm.
Ann. Ent. Soc. Amer., xviii, pp. 143–202, 35 figs.

——, 1927.
Un ennemi des rosiers. Le *Coraebus rubi*.
Ann. Epiphyties, xiii, pp. 48–78, 2 pls., 8 figs.

Greene, C. T., 1922.
An illustrated synopsis of the Puparia of 100 Muscoid Flies (Diptera).
Proc. U.S. Nat. Mus., lx, Art. 10, No. 2405, 39 pp., 20 pls.

——, 1925.
A tentative arrangement of the Muscoid Flies based on the Puparia.
Proc. Ent. Soc., Washington, xxvii, pp. 157–162, 1 pl.
The Puparia and Larvæ of Sarcophagid Flies.
Proc. U.S. Nat. Mus., lxvi, Art. 29, No. 2566, 26 pp., 9 pls.

Haviland, M. D., 1920.
On the Bionomics and Development of *Lygocerus testaceimanus* Kieffer, and *Lygocerus cameroni* Kieffer (Proctotrypoidea-Ceraphronidæ), parasites of *Aphidius* (Braconidæ).
Quart. J. Micr. Sci., lxv, pp. 101–127, 18 figs.

——, 1921.
On the Bionomics and Post-embryonic development of certain Cynipid Hyperparasites of Aphides.
Quart. J. Micr. Sci., lxv, pp. 451–478, 11 figs.

——, 1922.
On the Post-embryonic development of certain Chalcids, Hyperparasites of Aphides and remarks on the Bionomics of Hymenopterous Parasites in general.
Quart. J. Micr. Sci., lxvi, pp. 322–338, 7 figs.
On the Larval Development of *Dacnusa areolaris* Nees (Braconidæ), a parasite of Phytomyzinæ (Diptera), with a note on certain Chalcid Parasites of Phytomyzids.
Parasitology, xiv, pp. 167–173, 5 figs.

Howard, L. O., 1926.
The Parasite Element of Natural Control of Injurious Insects and its Control by Man.
J. Econ. Ent., xix, pp. 271–282.

Howard, L. O., 1929.
Aphelinus mali and its Travels.
Ann. Ent. Soc. Amer., xxii, pp. 341–368.

—— and Fiske, W. F., 1912.
The Importation into the United States of the Parasites of the Gipsy Moth and the Brown-tail Moth.
Bull. U.S. Dept. Agric. Bur. Ent., No. 91, 344 pp., 28 pls., 74 figs.

Imms, A. D., 1918.
Observations on the Insect Parasites of some Coccidæ. II. On Chalcid Parasites of *Lecanium capreæ*.
Quart. J. Micr. Sci., lxiii, pp. 293–374, 34 figs.

——, 1926.
The Biological Control of Insect Pests and Injurious Plants in the Hawaiian Islands.
Ann. Appl. Biol., xiii, pp. 402–423, 1 pl.

——, 1929.
Remarks on the Problem of the Biological Control of Noxious Weeds.
4th Int. Congr. Ent. Ithaca, N.Y., 1928, ii (Trans.), pp. 10–17.

James, H. C., 1928.
On the Life-histories and Economic Status of certain Cynipid Parasites of Dipterous Larvæ, with Descriptions of some new Larval Forms.
Ann. Appl. Biol., xv, pp. 287–316, 12 figs.

Keilin, D. and Baume Pluvinel, G. de la, 1913.
Formes larvaires et biologie d'un Cynipide entomophage. *Eucoila keilini* Kieffer.
Bull. Sci. Fr. Belg., xlvii, pp. 88–104, 2 pls., 5 figs.

—— and Picado, C., 1913.
Evolution et formes larvaires du *Diachasma crawfordi* n. sp. Braconide parasite d'une mouche des fruits.
Bull. sci. Fr. Belg., xlvii, pp. 203–214, 1 pl., 4 figs.

—— and Thompson, W. R., 1915.
Sur le cycle évolutif des Dryinidae, Hyménoptères parasites des Hémiptères homoptères.
C.R. Soc. Biol., lxxviii, pp. 83–87, 10 figs.

Sur le cycle évolutif des Pipunculides (Diptères) parasites intracoelomiques des Typhlocytes (Homoptères).
C.R. Soc. Biol., lxxviii, pp. 9–12, 11 figs.

Lotka, A. J., 1925.
Elements of Physical Biology.
Baltimore, Williams & Wilkins Co., xxx, 460 pp., 35 tables, 72 figs., 1 chart.

Lundie, A. E., 1924.
A Biological Study of *Aphelinus mali* Hald., a parasite of the Woolly Apple Aphid, *Eriosoma lanigerum* Hausm.
Mem. Cornell Univ. Agric. Expt. Sta., No. 79, 27 pp., 6 figs.

Marchal, P., 1906.
Recherches sur la biologie et le développement des Hyménoptères parasites. II. Les Platygasters.
Arch. Zool. exp. gén., iv, pp. 485–640, 1 pl.

——, 1908.
Utilisation des insectes auxiliaires entomophages dans la lutte contre les insectes nuisibles à l'agriculture.
Pop. Sci. Mon., New York, lxxii, pp. 352–370, 406–419.

Metcalf, C. L., 1916.
Syrphidae of Maine.
Bull. Maine Agric. Expt. Sta., No. 253 (Ent. paper 87), pp. 193–264, 9 pls., 1 fig.

Myers, J. G., 1927.
The Habits of *Alysia manducator* (Hym. Braconidae).
Bull. Ent. Res., xvii, pp. 219–229.
Natural Enemies of the Pear Leaf-curling Midge, *Perrisia pyri*, Bouché (Dipt. Cecidom.).
Bull. Ent. Res., xviii, pp. 129–138, 5 figs.

——, 1928.
Further Biological Notes on *Rhyssa* and *Ibalia*, parasites of *Sirex cyaneus*, Fabr.
Bull. Ent. Res., xix, pp. 317–323.
The Biological Control of Cotton Pests.
Empire Cotton Growing Rev., London, v, pp. 113–127.

——, 1929.
Further Notes on *Alysia manducator* and other Parasites (Hym.) of Muscoid Flies.
Bull. Ent. Res., xix, pp. 357–360.
Biological Control of the Froghopper—the present position.
Min. & Proc. Froghopper Invest. Comm., Trinidad, Part 14, pp. 217–219.
Biological Control.
Trop. Agriculture, Trinidad, vi, pp. 162–165.

Nielsen, J. C., 1909.
Iagttagelser over entoparasitiske Muscidelarver hos Arthropoder.
Ent. Medd., ix (2nd ser. iv), pp. 1–126, 4 pls.

——, 1911–1917.
Undersogelser over entoparasitiske Muscidelarver hos Arthropoder. I–VI.
Vidensk. Medd. naturh. Foren., Copenhagen, lxiii, pp. 1–26; lxiv, pp. 215–248, 42 figs.; lxv, pp. 301–304, 5 figs.; lxvi, pp. 211–220, 10 figs.; lxvii, pp. 9–24, 27 figs.; lxviii, pp. 23–36, 20 figs.

Pantel, J., 1910.
Recherches sur les Diptères à larves entomobies.
La Cellule, xxvi, fasc. 1, pp. 27–216, 5 pls., 26 figs.

Parker, H. L., 1924.
Recherches sur les formes post-embryonnaires des Chalcidiens.
Ann. Soc. ent. Fr., xciii, pp. 261–379, 39 pls.

—— and Thompson, W. R., 1925.
Notes on the Larvæ of the Chalcidoidea.
Ann. Ent. Soc. Amer., xviii, pp. 384–395, 3 pls.

—— — —, 1928.
Contribution à la biologie des Chalcidiens entomophages.
Ann. Soc. ent. Fr., xcvii, pp. 425–465.

Pemberton, C. E. and Willard, H. F., 1918.
Work and Parasitism of the Mediterranean Fruit-fly in Hawaii during 1917.
J. Agric. Res., xiv, pp. 605–610.

Perkins, R. C. L. and Swezey, O. H., 1924.
The Introduction into Hawaii of Insects that attack *Lantana*.
Bull. Hawaii. Sug. Planters' Assoc., Ent. Ser., No. 16, 83 pp., 1 pl., 7 figs.

Salt, G., 1930.
Natural Control of *Lucilia sericata*.
Nature, London, cxxv, No. 3145, p. 203.

Silvestri, F., 1919.
Contribuzioni alla conoscenza degli insetti dannosi e dei loro simbionti. V. La cocciniglia del nucciuolo (*Eulecanium coryli* L.).
Boll. Lab. Zool. Portici, xiii, pp. 127–192, 34 figs.

Smit, B., 1929.
The Sheep Blowflies of South Africa.
Bull. Dept. Agric. Un. S. Africa, No. 47, 27 pp., 3 pls., 16 figs.

Smith, H. S., 1912.
The Chalcidoid Genus *Perilampus* and its Relation to the Problem of Parasite Introduction.
Tech. Ser. U.S. Dept. Agric. Bur. Ent., No. 19, pp. 33–69, 8 figs.

——, 1919.
On some phases of Insect Control by the Biological Method.
J. Econ. Ent., xii, pp. 288–292.

——, 1926.
The Fundamental Importance of Life-history Data in Biological Control Work.
J. Econ. Ent., xix, pp. 708–714.

——, 1929.
Multiple Parasitism : Its Relation to the Biological Control of Insect Pests.
Bull. Ent. Res., xx, pp. 141–149, 1 fig.

On some phases of Preventive Entomology.
Scientific Monthly, xxix, pp. 177–184.

Smith, K. M. and Gardner, J. C. M., 1922.
Insects Pests of the Horticulturalist : Their Nature and Control. Vol. I : Onion, Carrot and Celery Flies.
London, Benn Bros., Ltd., vi, 76 pp., 42 figs.

Speyer, E. R., 1927.
An Important Parasite of the Greenhouse Whitefly (*Trialeurodes vaporariorum* Westwood).
Bull. Ent. Res., xvii, pp. 301–308, 3 pls.

——, 1929.
The Greenhouse Whitefly (*Trialeurodes vaporariorum* Westwood).
J. R. Hortic. Soc., liv, pp. 181–192, 9 pls.

Thompson, W. R., 1921.
Recherches sur les Diptères parasites.
Bull. biol. Fr. Belg., liv, pp. 313–463, 18 pls., 44 figs.

——, 1922.
Biologie.—Théorie de l'action des parasites entomophages. Les formules mathématiques du parasitisme cyclique.
C.R. Acad. Sci. Fr., clxxiv, pp. 1201–1204.
Entomologie.—Etude mathématique de l'action des parasites entomophages. Durée du cycle parasitaire et accroissement de la proportion d'hôtes parasites.
C.R. Acad. Sci. Fr., clxxiv, pp. 1433–1435.
Parasitologie.—Etude de quelques cas simples de parasitisme cyclique chez les insectes entomophages.
C.R. Acad. Sci. Fr., clxxiv, pp. 1647–1649.
Parasitisme.—Théorie de l'action des parasites entomophages. Accroissement de la proportion d'hôtes parasites dans le parasitisme cyclique.
C.R. Acad. Sci. Fr., clxxv, pp. 65–68.

——, 1923.
La théorie mathématique de l'action des parasites entomophages.
Rev. gén. Sci., Paris, 1923, 11 pp.
A criticism of the " Sequence " Theory of Parasitic Control.
Ann. Ent. Soc. Amer., xvi, pp. 115–128, 2 figs.
Recherches sur les Diptères parasites. Les larves primaires des Tachinidae du groupe des Echinomyiinae.
Ann. Epiphyties, ix, pp. 137–201, 12 pls.

——, 1924.
Théorie mathématique de l'action des parasites entomophages et le facteur du hasard.
Ann. Fac. Sci., Marseille (2), ii, pp. 69–89.
Les larves primaires des Tachinaires à œufs microtypes.
Ann. Parasit. hum. comp., Paris, ii, pp. 185–201, 279–306, 4 pls., 5 figs.

——, 1926.
Recherches sur les larves des Tachinaires *Sturmia*, *Winthemia*, *Carcelia* et *Exorista*.
Ann. Parasit. hum. comp., Paris, iv, pp. 111–125, 207–227, 2 pls.

Thompson, W. R., 1927.

A Method for the Approximate Calculation of the Progress of Introduced Parasites of Insect Pests.
Bull. Ent. Res., xvii, pp. 273–277.

On the Effect of Methods of Mechanical Control on the Progress of Introduced Parasites of Insect Pests.
Bull. Ent. Res., xviii, pp. 13–16.

——, 1928.

A Contribution to the Study of Biological Control and Parasite Introduction in Continental Areas.
Parasitology, xx, pp. 90–112, 5 figs.

A Contribution to the Study of the Dipterous Parasites of the European Earwig (*Forficula auricularia* L.).
Parasitology, xx, pp. 123–158, 6 pls., 4 figs.

——, 1929.

On the Relative Value of Parasites and Predators in the Biological Control of Insect Pests.
Bull. Ent. Res., xix, pp. 343–350.

On the part played by Parasites in the Control of Insects living in Protected Situations.
Bull. Ent. Res., xx, pp. 457–462.

On the Effect of Random Oviposition on the Action of Entomophagous Parasites as Agents of Natural Control.
Parasitology, xxi, pp. 180–188.

On Natural Control.
Parasitology, xxi, pp. 269–281.

—— and Parker, H. L., 1927.

The Problem of Host Relations with Special Reference to Entomophagous Parasites.
Parasitology, xix, pp. 1–34.

—— ——, 1928.

The European Corn Borer and its Controlling Factors in Europe.
Tech. Bull. U.S. Dept. Agric., No. 59, 62 pp., 3 figs.

—— ——, 1930.

The Morphology and Biology of *Eulimneria crassifemur*, an important Parasite of the European Corn Borer.
J. Agric. Res., xl, pp. 321–345, 7 figs.

Thomson, G. M., 1922.

The Naturalisation of Animals and Plants in New Zealand.
Cambridge, The Univ. Press, x, 607 pp.

Tothill, J. D., 1922.

The Natural Control of the Fall Webworm (*Hyphantria cunea* Drury), together with an Account of its several Parasites.
Bull. Canada Dept. Agric., 3 n.s. (*Ent. Bull.* 19), 107 pp., 6 pls., 99 figs.

Townsend, C. H. T., 1908.
A Record of Results from Rearings and Dissections of Tachinidae.
Tech. Ser. U.S. Dept. Agric. Bur. Ent., No. 12, pp. 95–118, 6 figs.

Trouvelot, B., 1924.
Recherches de biologie appliquée sur la teigne des pommes de terre et ses parasites et considérations générales sur l'utilisation des insectes entomophages en agriculture. Etude des conditions de pullulation des insectes.
Ann. Epiphyties, x, pp. 1–132, 4 pls., 32 figs.

——, 1925.
Directives à suivre dans l'importation pour les besions de l'agriculture, d'insectes entomophages étrangers.
Rev. Zool. agric. appl., Bordeaux, xxiv, pp. 125–148, 3 pls., 10 figs.

Volterra, V., 1926.
Variazioni e fluttuazioni del numero d'individui in specie animali conviventi.
Mem. Accad. Lincei, Cl. Sci. fis., mat. e nat., cccxxiii (6) 2, fasc. 3, 113 pp., 18 figs.

Wardle, R. A., 1929.
The Problems of Applied Entomology.
Manchester, The Univ. Press, xii, 587 pp., 4 pls., 29 figs.

Willard, H. F. and Bissell, T. H., 1926.
Work and Parasitism of the Mediterranean Fruit-fly in Hawaii in 1921.
J. Agric. Res., xxxiii, pp. 9–15.

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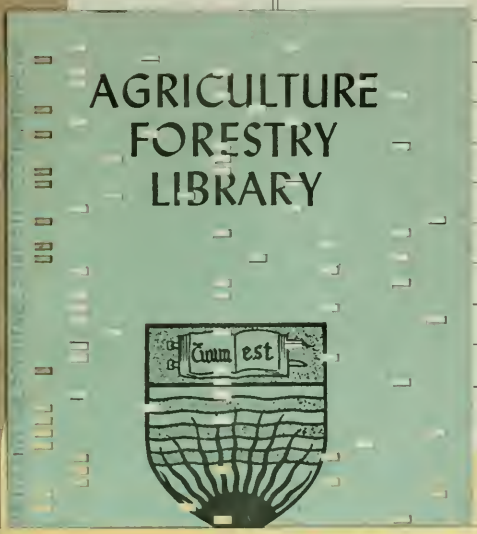

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